

Evaluation of the Vehicle Radar Safety Systems' Rashid Radar Safety Brake Collision Warning System

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PREFACE

This report was prepared by the U. S. Department of Transportation, Transportation Systems Center for the National Highway Traffic Safety Administration's Office of Crash Avoidance (NRD-50). The work was performed at TSC by the Operator Performance and Safety Analysis Division (DTS-45). The author wishes to thank Dr. Jose Bascunana and his colleagues in the Office of Crash Avoidance for their thoughtful criticisms and suggestions.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY	v
1.0 INTRODUCTION	1
1.1 Purpose of the VRSS	1
1.2 Description of the VRSS	2
2.0 DRIVERS' EVALUATION	5
2.1 Procedures.....	5
2.2 Performance in Various Driving Environments	6
2.2.1 Urban Driving at Low Speeds	6
2.2.2 Urban Driving at Higher Speeds	7
2.2.3 Heavy Traffic on Highways	8
2.2.4 Light-to-Moderate Highway Traffic	8
2.3 Performance with Specific Objects or Conditions	9
2.3.1 On-coming Traffic in Adjacent Lane	9
2.3.2 Surrounding Traffic	10
2.3.3 Merging into Traffic	10
2.3.4 Lane-Straddling Vehicles	10
2.3.5 Stationary Targets	10
2.3.6 Pedestians and Cyclists	11
2.3.7 Motorcycles	11
2.3.8 Precipitation	11
3.0 INSTRUMENTED MEASUREMENTS	12
3.1 Objectives	12
3.2 Instrumentation	13
3.2.1 Optical/Video System	15
3.2.2 Digital Speedometer	17
3.2.3 Police Radar Gun	17
3.2.4 VRSS Interface	19
3.3 Data Collection	19
3.4 Data Entry	20
3.5 Data Analysis	22

4.0 RESULTS	25
4.1 Probability of Warning Versus Closing Speed.	25
4.2 Braking Time Versus Closing Speed	26
4.3 Probability of Warning in Time to Brake	26
4.4 Problem Targets	33
5.0 ERROR ANALYSIS	34
5.1 Sample Composition.....	36
5.2 Range Measurements	36
5.3 Closing Rate	36
5.4 Set-up Errors	37
5.5 Target Alignment	39
6.0 CONCLUSIONS	39

APPENDIX 1: LISTING OF OBSERVED AND CALCULATED DATA

EXECUTIVESUMMARY

The Vehicle Radar Safety Systems, Inc. anti-collision system (VRSS) is designed to warn drivers of impending crashes with radar-reflective objects in front of them travelling in the same direction. It consists of a K-band-radar transmitter/receiver mounted in the front grill, a signal processor box installed wherever convenient, a speed sensor, and a dashboard-mounted display. Using both analog and digital circuitry, the radar echo from its narrow beam is analyzed for range and closing rate to targets. As large metallic objects such as vehicles are approached, various warning lights are illuminated. If the approach continues, a warning beeper sounds. The system is designed to ignore targets for which the closing rate is 30 mph or more in order to eliminate false alarms from road signs, etc. Hence it provides no reliable protection against vehicles emerging from side streets, nor against collision with on-coming vehicles. Stopped vehicles are detected only when the VRSS-equipped vehicle is travelling at less than 30 mph. Non-metallic objects such as pedestrians produce no warnings.

At the request of the NHTSA Office of Crash Avoidance Research, Mr. George Rashid, Jr., President of VRSS, agreed to lend two test units and arrange for their installation in NHTSA-owned cars. The evaluation was conducted by the Transportation Systems Center.

The evaluation was divided into two phases. In the first, one of the test vehicles was driven about 3000 miles by the author and other TSC personnel on public roads. The performance of the VRSS unit was observed in the course of approaches toward thousands of vehicles. This vehicle was equipped with a police-radar speed gun modified to show closing speed, an accurate digital speedometer, auxiliary displays for the VRSS, a brake-pedal-status indicator, and a video system to record all of the above along with a stopwatch display and a view through the windshield. By playing back the several hours of accumulated video tape in slow motion, one could gain a clear understanding of the behavior of the VRSS. About twenty-five minutes' worth of excerpts from this video tape have been copied onto a tape which complements this report.

Based on the qualitative observations, it was concluded that the VRSS usually detects vehicles in time to provide a useful warning of imminent' collision so long as the closing speed is not too great. It can substantially reduce the probability of striking a leading vehicle when ones attention is distracted from the road ahead. During merges onto busy highways, when a driver is frequently looking over his left shoulder, the VRSS is particularly valuable in warning if a leading vehicle slows. In approaching other vehicles at Interstate highway speeds, the VRSS gave adequate warning of impending collisions in almost all cases when the closing rate was under 10 mph. However, at 20

mph closing speed, about half the time it was necessary to initiate evasive action before the VRSS generated an audible warning.

In lower-speed driving environments, especially stop-and-go urban travel, the warning beeper is triggered much more frequently than in highway driving. While these warnings are caused only by vehicles in ones path, i.e., they are actually not false alarms, they are usually superfluous because they occur when one is already braking.

The principal objective of the second stage of the evaluation was to assess the performance of the VRSS device quantitatively. Procedures were devised to permit measurement of the exact time and distance from target at which the VRSS unit produced its various warnings as each of more than 350 vehicles was overtaken in the course of several hours' driving on Interstate highways. Performance measures derived from these data included: (1) probability of warning prior to the initiation by the test driver of braking or lane-change as a function of closing speed for all vehicles encountered and by vehicle class, (2) average warning time in seconds prior to impact, and (3) average distance from target the moment warning was given, Although data were recorded from the warning lights as well as the beeper, only the latter was scored because the TSC drivers found the lights were too small and too dim to be effective in daylight conditions. .

Usable data were generated for 237 cases. Virtually all of the trucks prompted audible warnings from the VRSS before it was necessary to begin braking or lane-changing. However, for about a sixth of the passenger-car targets, audible warnings occurred only after a corrective maneuver was initiated.

To avoid actually colliding with targets during the road tests, lane changes rather than braking were used in most cases. Had only braking been permitted, when the target was also braking the audible warnings given by the VRSS would have come too late in a higher percentage of the cases. The VRSS beeper provided adequate warnings (i.e., occurring before it was necessary for the driver to take action) for braking over the full range of closing speeds only when road speeds below 30 mph were combined with dry pavement and driver reaction time of about one second. On dry pavement at highway cruising speeds, audible warnings were sufficient for braking only about 60% of the time for 5 mph closing speeds and slightly less than half the time for 10 mph closing speed. However, if degraded conditions, such as wet pavement, were assumed, calculations of required braking distances show that the VRSS beeps would provide adequate warning only for closing speeds of 5 mph or less combined with low road speeds. For icy roads or seriously impaired drivers, the VFW would provide no useful warnings whatsoever.

All of the data cited above were based upon tests of a single unit, as installed, adjusted and delivered to NHTSA by VRSS, Inc. and road tested by the firm's chief engineer shortly before data collection began. The second vehicle was intended only as a back-up and was not required. Different results might have been obtained with a different unit, or by readjusting the sensitivity and alarm-delay controls of the tested unit. Conducting the tests at some other locale with a different proportion of poor-reflecting vehicles, or with different road contours could also have produced significant changes in various performance measures as discussed in Section 5 of this report.

Other conclusions of the study may be summarized as follows:

- . In most cases, when a moving vehicle is being overtaken on a collision course at closing speeds of less than 25 mph, the VRSS will provide a timely audible warning. The probability is very high for a truck, but is reduced for a passenger car, especially one with narrow, vertical tail-light reflectors.
- . At highway speeds, the VRSS does not respond to fixed or slow moving vehicles crossing perpendicular to the path of the test vehicle, nor to vehicles being over-taken at speeds of more than 30 mph.
- . Averaged over all of the 237 valid cases, audible warnings occur at least three seconds before possible impact. At closing speeds below 10 mph, warning time increases to five seconds or more.
- The average distance to target at which audible warnings occur ranges from around 60 feet at speeds below 50 mph to about 130 feet at 72 mph, and also increases with closing speed.
- . Road curvature, crest, sag or any other condition resulting in misalignment between the centerlines of the target and test vehicles by more than a few feet can severely reduce warning time or eliminate beeping completely.

The effects of the VRSS on driver behavior and the effects on the VRSS of environmental factors such as precipitation and electromagnetic or radio-frequency interference were not investigated.

1.0 INTRODUCTION

This evaluation of the Vehicle Radar Safety Systems' anti-collision device (hereafter VRSS) was undertaken by the Operator Performance and Safety Analysis Division of the Transportation Systems Center at the request of the National Highway Traffic Safety Administration's Office of Crash-Avoidance Research.

While the NHTSA Office of Research and Development has a longstanding interest in the evolution of anti-collision systems, it must be recognized that the device under test in this project received no government funding. Its development was initiated by the late George Rashid, Sr., who founded Vehicle Radar Safety Systems. This evaluation was sought by NHTSA, which negotiated arrangements for the tests with Mr. George Rashid, Jr., the current president of the firm. Two collision warning systems were loaned to the government and installed in government-owned vehicles by VRSS. Mr. William D. Goodson, Chief Engineer for VRSS, visited TSC to inspect the installation, ascertain that the unit to be tested was operating properly, receive a briefing on the evaluation procedures and discuss design objectives.

The manufacturer has developed two versions of the product, one of which provides only warnings of impending collisions while the other also applies braking. Only the former was evaluated in this-project.

1.1 Purpose of the Rashid Anti-collision System

Before beginning discussion of the goals of this evaluation, it is useful to consider the design goals of the Rashid device. Its purpose is to warn drivers of radar-reflective objects of significant size in the path of their vehicles. It is intended to operate successfully under all weather conditions.

In order to avoid false alarms from vehicles in adjacent or opposing lanes of traffic the beam width was designed to be quite narrow. In practice, this choice of beam width reduces detection range on curving roads.

False alarms are also minimized by restricting operation of the system to vehicle speeds greater than about 10 mph and closing speeds of less than 30 mph. The system does not begin operating until vehicle speed rises above 10 mph which prevents false alarms in low-speed turning maneuvers as in parking lots. It cuts off as vehicle speed drops under 10 mph to shut off the beeper when approaching stopped cars at a red light. At highway speeds, stationary objects, such as road signs, can not cause false alarms because they are excluded by the 30 mph closing speed criterion.

The Rashid system protects chiefly against rear-end collisions with the vehicle ahead. It was not intended to warn of vehicles entering the roadway from side streets, The prime objective in its design is to warn the driver who is drowsy or whose attention has been distracted away from the road ahead that a leading vehicle has begun slowing down.

1.2 Description of the VRSS

The Rashid Collision Warning System consists of four separate assemblies: (1) a miniaturized radar transmitter/receiver (shown mounted in the grill of the test vehicle in Figure 1.2-1); (2) a signal processor box (shown mounted under the hood in Figure 1.2-2); (3) a dashboard display with four light-emitting diodes (LED's) and a beeper (shown attached to the dashboard in Figure 1.2-3) and speed sensor pick-up coil (shown mounted adjacent to a ring of magnets on the drive shaft in Figure L2-4). The system is ordinarily wired to the ignition switch so that it is automatically enabled whenever the vehicle is in use. At the owner's option it may also be wired with a separate switch.

In operation the green LED lights whenever the vehicle's speed exceeds approximately 10 mph to show that the radar is active. The yellow LED illuminates only if a vehicle or other large metallic object is present directly ahead and within a certain distance, This distance varies with speed, with the microwave reflectivity characteristics of the object and also with the settings of certain adjustments made by the dealer during the installation process.

If a target vehicle is within detection range and getting closer one or (usually) both of the red LED's on the display will glow. The LED labelled "Warning" is designed to trigger before the "Danger" LED but in many cases they come on simultaneously.

Unless the driver quickly reduces the rate of closing speed by braking or taking evasive action, a warning beeper will be triggered shortly after the "warning" LED. The time delay depends on the rate of closing speed and also upon the "time-delay" adjustment set by the dealer during installation. This beeper is two-tone device and produces a sound pressure level of about 102 dB (A-weighted) at the case or about 88 dB (A-weighted) at the driver's ear. This sound is clearly audible above any engine noise or even very loud stereo systems. The level is not user adjustable.

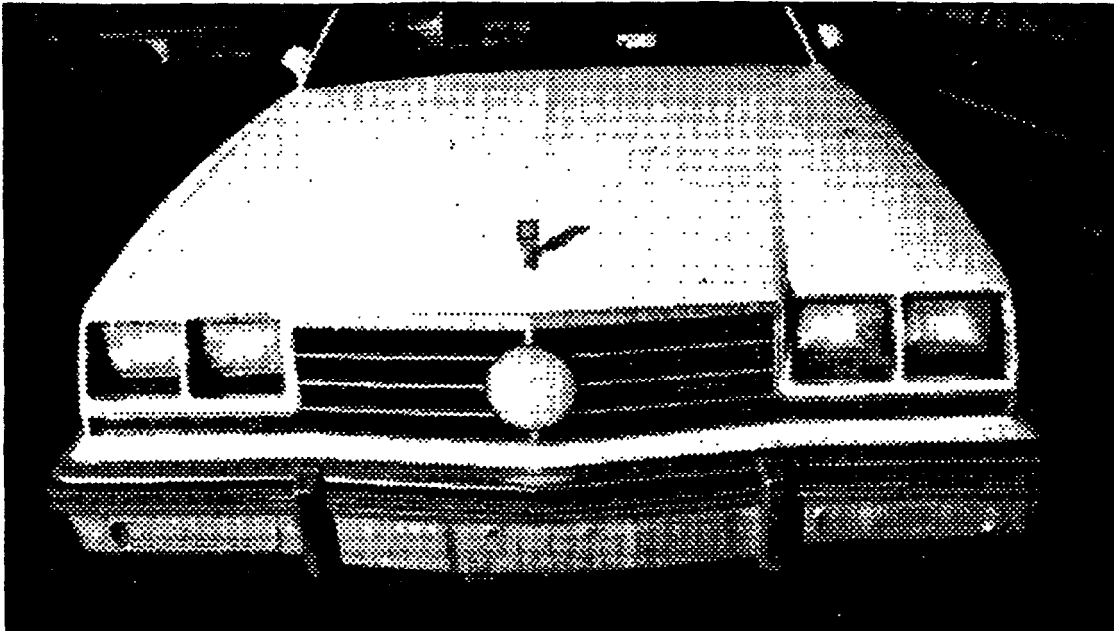


Fig. 1.2-1: VRSS Mounted in hick LeSabre

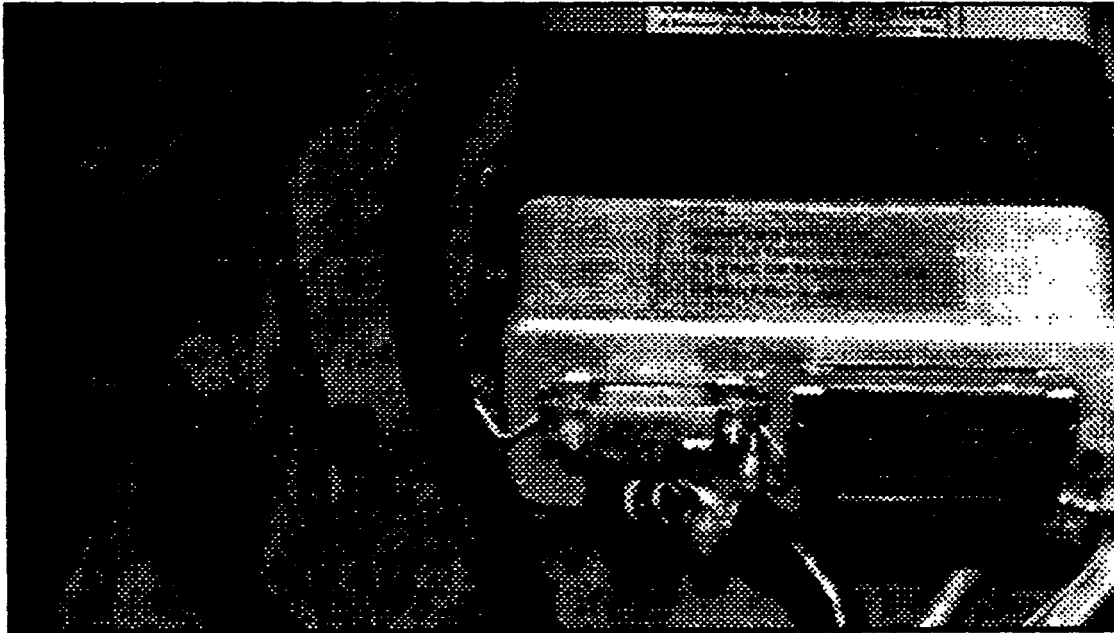


Fig. 1.2-2: Signal Processor

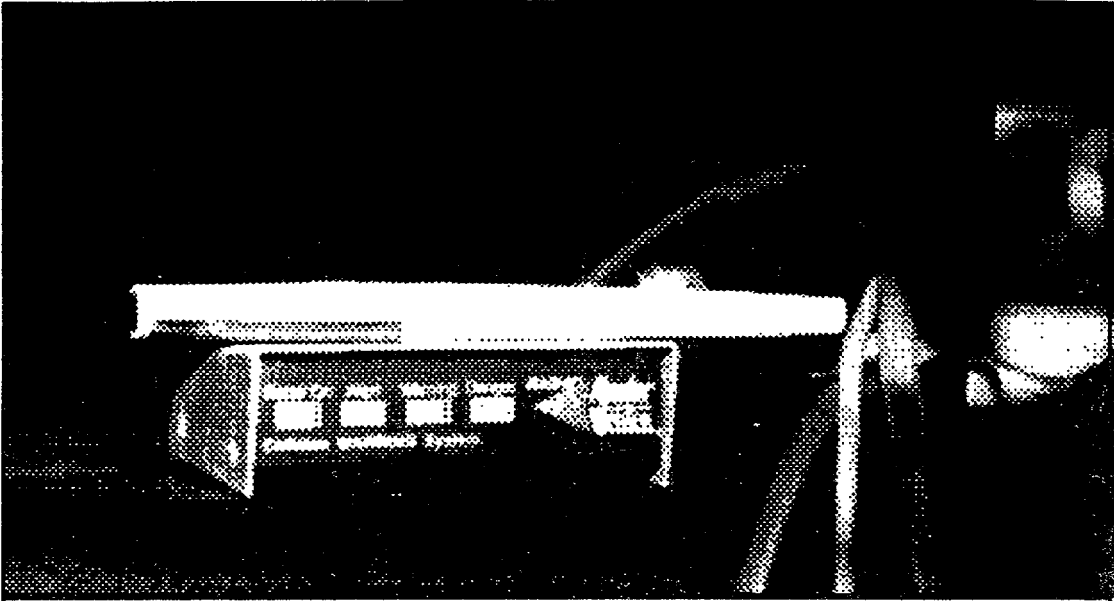


Fig. 1.2-3: Dashboard Display

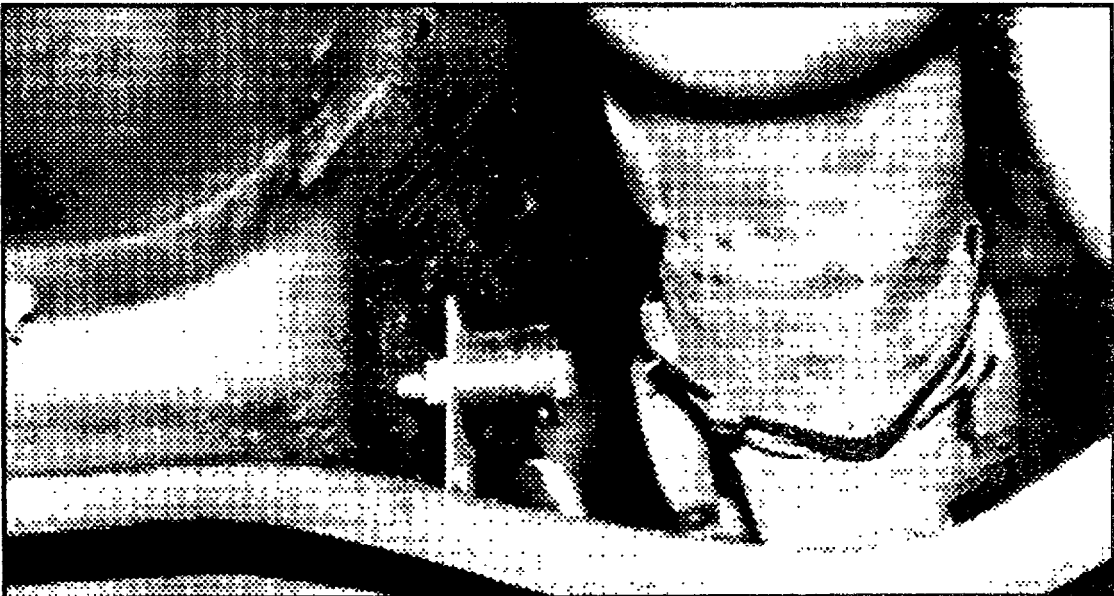


Fig. 1.2-4: Speed Sensor Pickup Coil

2.0 DRIVERS' EVALUATION

The purpose of this first task was to establish a general qualitative understanding of VRSS operation and to determine parameters for subsequent quantitative evaluation. In the course of at least 3,000 miles of test driving on city streets and limited-access highways, TSC personnel observed the performance of the VRSS unit. Particular attention was devoted to any instances of false alarms and failures to warn of impending collisions. Driver comments on the adequacy of displays and audible warning devices, superfluous alarms, etc. were also noted.

All of the following situations were included in this driving: (1) oncoming traffic in adjacent lane during turning maneuvers of the test vehicle, (2) surrounding traffic merging into and out of the lane of the test vehicle, (3) test vehicle merging into and out of traffic streams, (4) lane-straddling targets, (5) stationary targets outside the collision course, and (6) approaches to targets in the test vehicle's lane at a wide range of closing speeds.

2.1 Procedures

Most of the test-driving mileage was done during a series of round trips between Cambridge, Massachusetts and Warwick, Rhode Island. Most of the mileage was accumulated on Interstate 95, but various urban streets and arterials were travelled as well. Altogether, more than 3000 miles of driving were accrued.

In the course of this driving, many hundreds of vehicles were approached. Closing speed was deliberately varied over the range from one mile per hour to more than 20. Higher closing speeds could be tested only in light traffic when there was adequate room for evasive maneuvers.

Initially a primary purpose of the project was to discover under what conditions a radar warning system might produce false warnings. However such false alarms almost never occurred except for the superfluous warnings while braking for stopped vehicles in urban driving. Instead the evaluation focused primarily upon the adequacy of warnings in various conditions.

Several hours' of video tape, recording approaches to more than 200 vehicles, were produced. These tapes included a continuous stop watch display as well as readouts of test vehicle speed and closing rate to target. This instrumentation is described in greater detail in Section 3.2. By reviewing this tape in slow motion or freeze-frame one could easily determine precisely how much warning time the VRSS unit provided prior to the commencement of a braking or lane-change maneuver.

2.2 Performance in Various Driving Environments

It was hypothesized that the VRSS might be susceptible to frequent false alarms caused by vehicles in adjacent and/or opposing lanes, signs and other roadside appurtenances, debris, precipitation, etc. Were this the case, performance would be strongly affected by traffic density and the roadside environment. Hence the test driving program was planned to include a wide variety of situations. In the course of some 3,000 miles of testing, all of these were encountered. However, as will be explained and documented below, VRSS false-alarms, i.e., those occurring when no vehicle was present directly in front of the test vehicle, were not significant under any circumstances and the vast majority of the video taping was confined to interstate highway driving. Superfluous alarms, i.e., those sounding after braking had already commenced, were common in urban driving and were described as annoying by the TSC test drivers,

In the following discussion of VRSS performance, frequent statements occur relating to whether the warning of impending collision was adequate or inadequate. By “adequate” the author means that the audible alarm (beeper) triggered prior to the onset of braking or the beginning of a lane-change maneuver. At the higher end of the range of closing speeds, i.e., greater than 15 mph, this evasive maneuver usually had to be delayed to under five seconds before impact would have occurred. Quite often at these speeds, only a lane change maneuver would avoid collision within the warning time given by the VRSS. That is, some of the warnings that are characterized as adequate in the following discussion would have been described as inadequate if only braking maneuvers had been allowed.

2.21 Urban Driving at Low Speeds

About a thousand miles of driving were accumulated on the heavily travelled streets of the greater Boston area over a six-month period. Most of this mileage occurred on arterials.

In discussing the performance of the VRSS in urban driving, it is helpful to differentiate between the low-speed (under 30 mph) and the higher speed environments because of the 30-mph-closing-speed cutoff filters in the system. In the low-speed situation, once the radar became active at around 10 mph, all vehicles and other largemetallic objects in the beam are detected. Furthermore, it is generally the case that when speeds are held below 30 mph, traffic is quite dense and congested. Under these conditions it is virtually impossible for large speed differentials to exist between the VRSS-equipped vehicle and others on the road. Not surprisingly, the VRSS provides adequate warnings of impending collisions nearly all the time at low speeds. The only in-

stances in which warnings are inadequate in the low-speed environment are those in which substantial road curvature removes target vehicles from the beam area.

Because short-radius turning maneuvers are common at low speeds, situations in which detectable targets appear in the beam but not in the driver's intended path are frequent. These give rise to false-alarms. Figure 2.2.1-1 (from the Rashid Owner's Manual) illustrates one of the most familiar. In the thousand miles of test driving on urban streets, only a handful of instances were noted in which objects other than vehicles produced false alarms. These were either guard rails or metal-clad buildings directly in the path of the beam.

In the opinion of the TSC drivers, the greatest fault of the VRSS (as installed in the test vehicle) was the superfluous beeping it produced as stopped vehicles were approached with brakes applied. The Owner's Manual suggests that this may be avoided by approaching stopped vehicles more cautiously. This would require dropping below 10 mph about 60 feet back from a stopped vehicle. Such extreme caution is rarely practiced in urban traffic.

The performance of the VRSS in low-speed urban traffic is illustrated in the first six minutes of the video tape complementing this report.

2.2.2 Urban Driving at Higher Speeds

In urban traffic moving continuously at speeds above 30 mph, the annoyance of frequent beeping for stopped vehicles disappears. In this sort of driving environment, the VRSS is very effective at sounding warnings for slowing vehicles provided that the speed differential is less than 10 mph, which is commonly the case.

The major shortcoming of the VRSS at higher urban speeds is that it confers no warning at all of vehicles pulling out from side streets or parking spaces nor of vehicles which are stopped or travelling at unusually low speeds. The Owner's Manual notes these constraints under "Some Special Features you should know about." As

noted in the discussion in Section 1.1, this design decision to eliminate warning of objects when the closing speed is greater than 30 mph is a deliberate one made in the interest of eliminating false alarms.

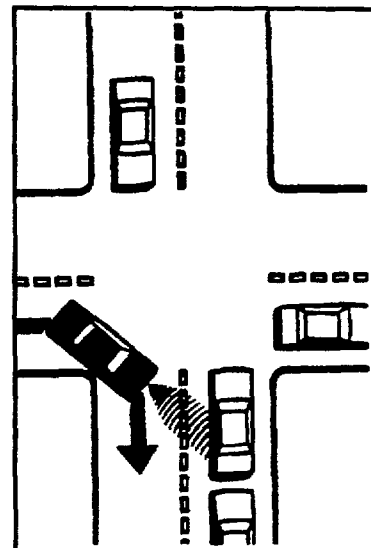


Fig. 2.2.1-1: Illustration from the Owner's Manual depicting a turning maneuver in which unnecessary warnings may occur.

The second six-minutes of the complementing video tape illustrate performance in this environment.

2.2.3 Heavy Traffic on Highways

During heavy traffic periods on highways, the value of the VRSS is much the same as on the faster urban roads. Traffic congestion forces drivers to travel at about the same speed. Hence closing speeds are small and the VRSS almost always provides an adequate warning when a leading vehicle slows down,

By and large, the heavy-traffic driving environment is not one in which drivers are very likely to be dozing. The frequent beepings which may occur when headways are close are largely superfluous. However, there is one situation in heavy traffic in which the VRSS can be of some value. In merging into heavy traffic, a driver's attention is frequently directed over his left shoulder. In this condition a sudden slowing by a leading vehicle can easily lead to a collision. The VRSS is quite effective at preventing accidents under these circumstances so long as speed differentials are not too great.

The third six-minute segment of the complementing video tape demonstrates VRSS performance in rush-hour traffic on I-95.

2.2.4 Light to Moderate Highway Traffic

The performance characteristics of the VRSS are most easily tested at high speed in fairly light traffic. The great bulk of the video tape being shot for subsequent quantitative analysis in the second phase of this project has been made under the following conditions: (1) rural Interstate highway with three travel lanes in each direction; (2) light to moderate traffic; (3) dry or damp road surface (free from standing water). When these conditions are met, it is possible to approach other vehicles at closing speeds of 20 mph or greater with the certainty that there is plenty of room for prudent evasive actions and that no additional vehicles may suddenly appear in the path of the test vehicle.

Based on about 1500 miles travelled under such circumstances, the author offers the following observations: (1) At closing speeds of 5 mph or less, the VRSS can be relied upon for adequate warnings from nearly all vehicles on the road. (2) For closing speeds in the 5-10 mph range, the probability of an adequate warning is very high. Only a few vehicles, those with convex, sloping rear-end sheet metal. or narrow vertical tail light assemblies, are not always detected in time to provide an adequate warning. The Volkswagen Beetle and the Cadillac are among the most familiar examples of such cars. (3) As closing speeds rise through the 10 to 20 mph range the proportion of

vehicles detected with adequate warning time steadily declines. At 20 mph closing speed, a substantial proportion of passenger cars do not provide sufficient warning. (4) As closing speeds exceed 20 mph, the chance of an adequate warning falls rapidly. At these speeds only large trucks and a few other vehicles which happen to be particularly good microwave reflectors are likely to be detected in time.

The final six minutes of the complementing tape are of moderate-density, high-speed traffic.

2.3. Performance with Specific Objects or Conditions

In the course of planning for this project, several particular kinds of driving maneuvers or targets were mentioned which might give rise to false alarms or conversely, go undetected. It was therefore agreed that test drivers would pay particular attention to the behavior of the VRSS in the situations described below and that their observations would be documented in this report.

2.3.1 On-coming Traffic in Adjacent Lane during Turning Maneuvers

As noted in Section 2.2.1, audible warnings from the VRSS may occur in low-speed turning maneuvers whenever large metallic objects appear in the radar beam at distances of less than about 100 feet. In intersection maneuvers beeping may ensue if the traffic in the opposing lane is stopped, but seldom if it is moving. In the latter case, the closing rate is usually above the 30 mph cutoff. In general the sides of passenger cars do not reflect microwaves as well as the front or rear surfaces. Hence, in order for beeping to arise, the VRSS-equipped vehicle must usually be quite close, i.e., within 50 feet, of the target. Overall, superfluous beeping during turning maneuvers seems to happen about 10% of the time. This fraction would be higher on narrow, congested streets with lots of parked cars near the intersections. In lower-density areas with broad streets and no on-street parking, this fraction would fall near zero.

2.3.2 Surrounding Traffic Merging into and out of Test Lane

When an object produces a sufficiently strong radar echo to be detected, the VRSS responds very quickly, that is in a minor fraction of a second. Therefore, when a leading vehicle abruptly merges into the lane of the test vehicle, its presence is indicated immediately by the yellow LED alert light if it is within range. If the speed differential between the target and the test vehicle is greater than zero and less than 30 mph, the red LED's and beeper will also trigger. The LED's can trigger almost instan-

taneously if the speed differential is substantial, say 15 mph. The beeper is delayed somewhat, depending upon the setting of the internal “time-delay” adjustment.

Should a vehicle which is producing a warning signal suddenly change lanes, the warning ceases immediately.

2.3.3 Test Vehicle Merging into and out of Traffic

The case where the test vehicle is merging in and out of other traffic is entirely symmetrical with the above. Vehicles within the detectable range produce immediate alerts, Additional warnings and beeping begin almost immediately if the closing rate is substantial.

2.3.4 Lane-Straddling Vehicles

Since the VRSS beam width appears to be only a few feet, a target vehicle can become undetectable by travelling well off the lane center. The amount of displacement from the centerline of the beam required to escape detection varies with the reflectivity characteristics of different vehicles, ranging from about three feet to six feet. Thus if the test vehicle were to overtake an off-center target, the two might collide without any warning from the VRSS under some conditions. Even if the target vehicle were initially far enough off-center to allow clearance, such a lane-straddler may swerve back to normal lane position at any moment. Although it would then be detected, the warning might come too late. Hence, the VRSS should not be relied upon in this situation.

2.3.5 Stationary Targets Outside the Collision Course

Because of the narrow beam width of the VRSS, there was not a single instance of an object not directly in front of the test vehicle producing an alarm. In instances of road curvature or turning maneuvers, stationary targets could produce beeping under the following conditions: (1) test vehicle speed between 10 and 30 mph; (2) metallic target large enough to reflect substantial microwave energy, generally vehicles or metal buildings; (3) target close to course of test vehicle, generally less than 50’.

2.3.6 Pedestrians and Cyclists

The VRSS does not respond to non-metallic objects such as pedestrians. Bicycles do not reflect enough microwave energy to be detected at any useful range. No instances of warnings from either of these were noted at any time during the test driving.

2.3.7 Motorcycles

Most of the test driving was conducted during the colder months of the year. Hence motorcycles were much less common than in the summer or in warmer climates. Only one encounter with motorcycles was recorded during the entire 3000 miles of test driving. In that instance, a side-by-side pair of Harley-Davidsons, both fitted with large luggage carriers, was detected at a distance of more than 100', which provided more than ample warning. Whether the VRSS provides sufficient warning for smaller machines travelling alone remains to be determined.

2.3.8 Precipitation

Because water droplets are both absorbers and reflectors of microwave energy, it has been hypothesized that VRSS performance could be degraded in foul weather. However no such degradation was observed during any of the test driving through light rain and light snow. Unfortunately, no heavy or even moderate precipitation was encountered. Because such weather is comparatively rare in the Boston area and because high-closing-speed approaches to other vehicles could not be driven safely under those conditions, it is not likely this question can be settled through road testing.

3.0 INSTRUMENTED MEASUREMENTS

3.1 Objectives

The primary objective of the second phase of the project was to assess quantitatively the ability of the VRSS device to warn of impending collisions in time for the driver to take evasive action. Initially, it was suggested that such tests should be carried out using standard radar reflectors as fixed targets with known cross-sections. However, during Phase I, it became apparent the radar reflection characteristics of different vehicles vary enormously. Although passenger cars may on the average be approximated by a standard one-square-meter target, such a test would give misleading results because the vehicles with much different effective cross-sections would not be represented. Defining an appropriate distribution of radar-cross-sections to match that of the actual vehicles in use would vastly exceed the scope of this project.

Three aspects of VRSS design also serve to frustrate attempts to test it against fixed targets: (1) the low-speed cutoff prevents testing at speeds below 10 mph, which are in fact the closing speeds most commonly experienced in highway driving; (2) the anti-false alarm circuits eliminate responses to targets being approached at 30 mph or more; and (3) the effective detection range varies with road speed and closing rate. Because of these constraints, testing against fixed, standardized targets was rejected as impractical.

Instead, the first objective of this testing was the determination of the probability with which the VRSS could provide warning of impending collision prior to the initiation of evasive action as various vehicles were overtaken at closing speeds ranging from less than two to more than 20 miles per hour. It was recognized that the decision about when evasive action must be taken is subjective. Hence additional rating scales, described in Sections 4.2 and 4. were also devised. All of the scoring was based on the audible warnings from the VRSS, since it was the consensus of the TSC drivers that the LED's were not useful in day light.

From the Phase I testing it was already apparent that the VRSS unit could provide such warnings with near certainty ~~when~~ the target vehicles reflected a strong signal or when the closing speeds were low. **Conversely**, it was noted that a few specific make-model vehicles were seldom **detected in time for** the VRSS to provide a useful warning, apparently because the **design of their taillight** reflectors is such that they do not return very much energy at the operating frequency of the VRSS. Likewise, high speed differentials and/or substantial misalignment of vehicle centerlines could be expected to result in a reduced probability of timely warning from the VRSS.

Since the probability distributions of warnings referred to the onset of evasive action depend upon the driver's judgement as to when evasive action must be taken, a more objective set of measures is also needed. Thus the second objective was the determination of the probability distribution of warning time in seconds prior to impact. Again these distributions would vary with closing speeds and target reflectance characteristics.

Thirdly, an evaluation of whether the VRSS could provide useful warnings on wet or icy roads and in situations in which braking was the only available response was performed. These performance measures were calculated from the dry road data.

3.2 Instrumentation

The test vehicle was fitted with two video cameras and a recorder. The camera outputs were combined in a special effects generator to provide a continuous "through-the-windshield" view in the upper half of the picture, while the lower half showed the displays of various instruments. These included: a digital speedometer for the test vehicle, a police radar gun aimed to show closing speed with the vehicle just ahead, a stopwatch and six pilot lights indicating the status of the three levels of warning from the VRSS unit, the beeper, brake-pedal actuation and a driver-controlled event marker. Driver comments and beeper signals were recorded on the audio tracks. Figure 3.2-1 shows all of the instrument displays except the stopwatch, which is internally generated by the video camera. The right front seat of the test vehicle with both the instrumentation and the video gear installed is depicted in Figure 3.2-2 with an example of the combined video output in Figure 3.2-3.

The VRSS dashboard display unit was placed inside a custom-built interface which contained four phototransistors to monitor the status of each of the LED's and a microphone and tonedetector circuit to monitor beeping. The outputs of these circuits were fed to two repeater displays. One repeater was mounted on the dashboard for convenient viewing by the driver. The other was placed before the instrumentation camera, as noted above.

Because the configuration of instruments and video cameras used required a distance of 44" from windshield to headrest (see Figure 3.2-2) as well as a smooth ride to prevent jiggle in the picture, only the 1980 Buick LeSabre was used in the evaluation. The second vehicle fitted with a VRSS unit, an AMC Spirit, could not accommodate the test equipment. It was given only two cursory test runs totalling about 10 miles. The performance of its VRSS system seemed similar to that in the Buick.

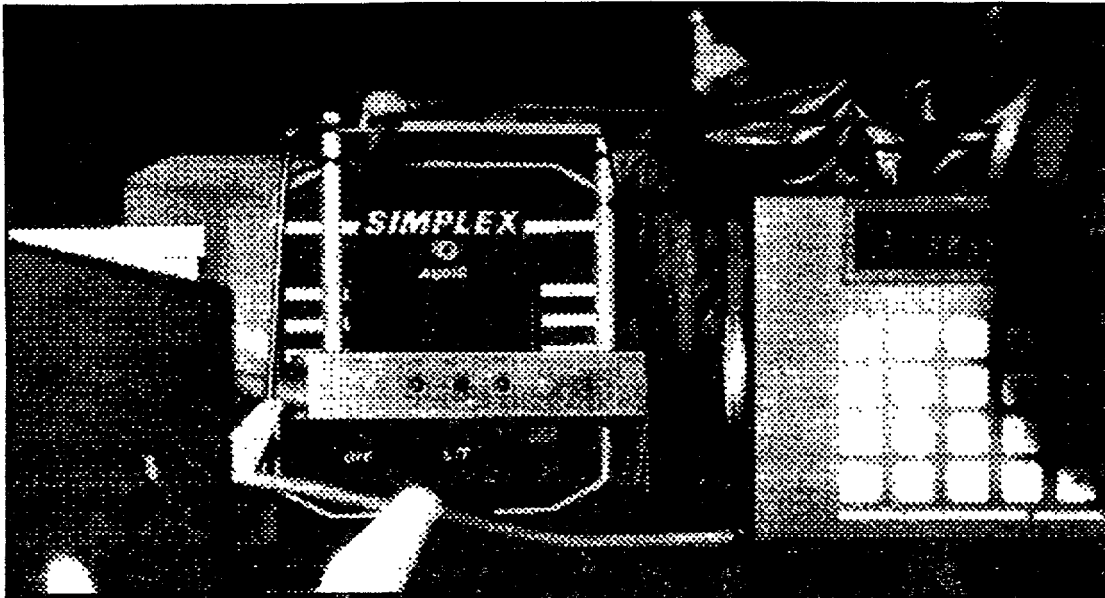


Fig. 3.2-1: Close-up View of Instrument Displays

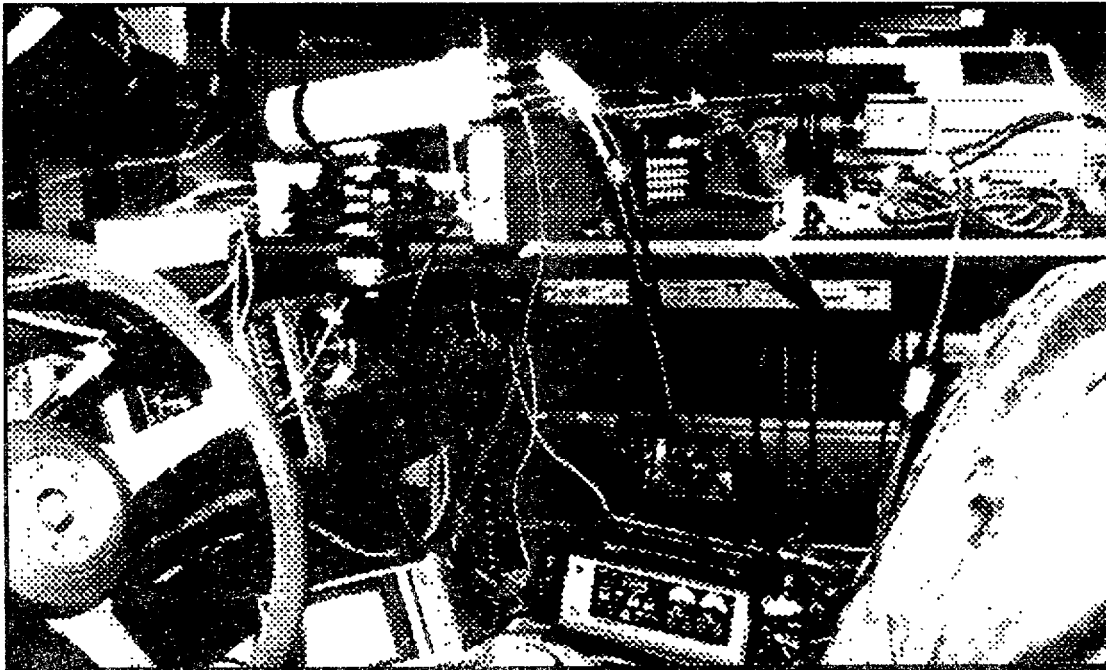


Fig. 3.2-2: Data Collection Equipment

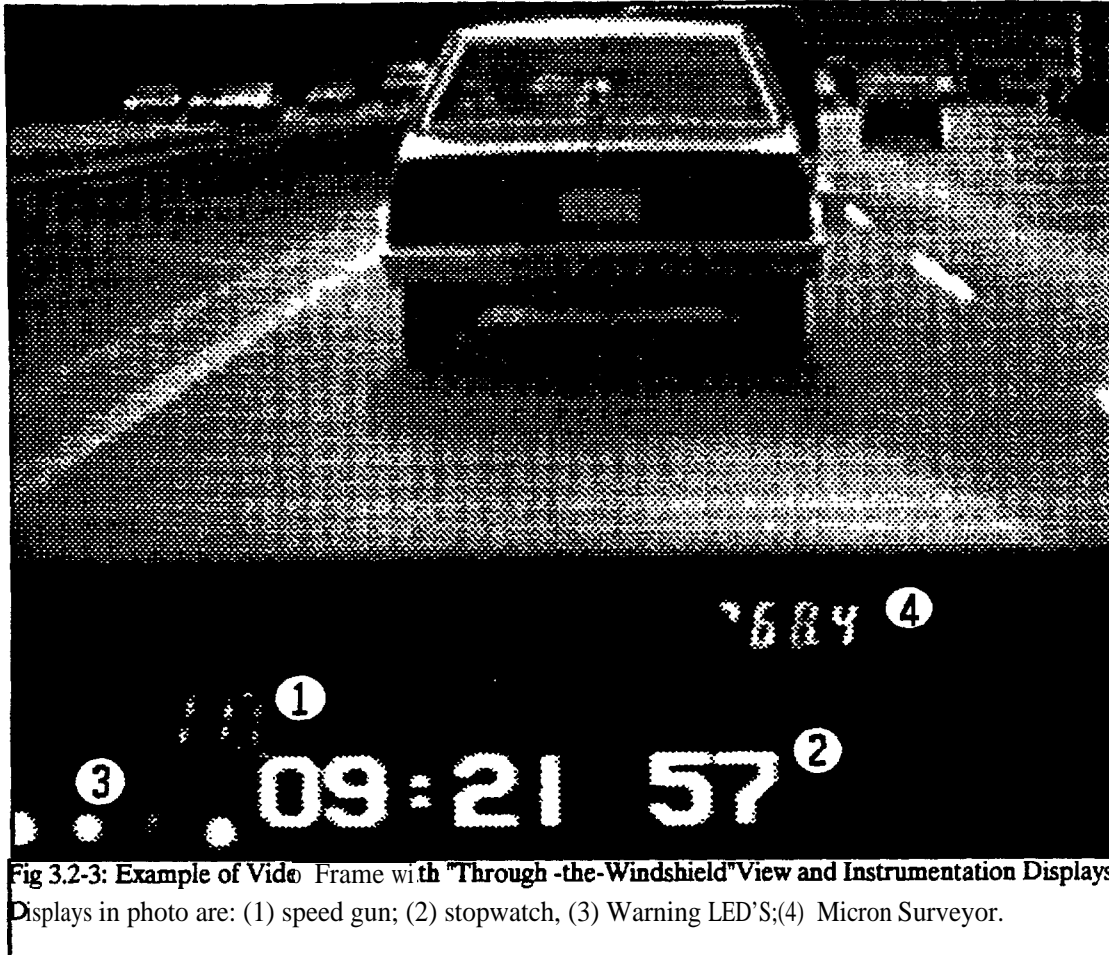


Fig 3.2-3: Example of Video Frame with "Through-the-Windshield"View and Instrumentation Displays
 Displays in photo are: (1) speed gun; (2) stopwatch, (3) Warning LED'S;(4) Micron Surveyor.

3.2.1 Optical/Video System

The "through-the-shield" view was provided by a Panasonic WV-132 color CCD surveillance camera. This type of camera is essential for this application because it combines the small physical size and low weight required to fit into the available space with immunity to damage from facing directly into the sun and with the capability to accept external synchronization signals necessary for split screen images. It was fitted with a fixed, 25mm lens, whereas the normal lens for this camera is 16mm. Thus a moderate telephoto image was produced. A vehicle 20 feet ahead filled about three-quarters of the screen from side to side, while one at 180' occupied only about 10% of the frame width.

The optical/video system was calibrated according to the following formula:

$$R = F * (1 + (Wt/Wi)) - Lh$$

where

- R = range in feet from front of car
- F = factor representing product of focal length & video magnification
- Wt = width of target
- Wi = width of image on monitor
- Lh = distance from front of car to camera

The value of F was measured at nine points in 20' increments ranging from 20' to 180' using a stationary, 70"-wide Plymouth Voyager van as the target. Because it would be unsafe to approach target vehicles as close as 20 feet at highway speeds, the data for that distance were not used in calculating the average value of F, which was 2.305. The data were:

True Range (ft)	Image Width (mm)	F-Value	%Deviation from avg
20	154	2.15	-6.7
40	89	2.24	-2.8
60	63	2.29	-0.7
80	49	2.33	+1.1
100	39	2.30	-0.2
120	33	2.31	+0.2
140	28	2.36	+ 2.4
160	24	2.32	+0.7
80	22	2.29	-0.7

These errors derive mainly from non-linearities in the video hardware.

The instrumentation camera was a Panasonic WV-3250/8AF. The only important selection criteria for this camera were its ability to generate internally a stop-watch display and its wide-angle macro lens,

Both cameras were mounted to a sheet of three-quarter inch Baltic Birch plywood which had been custom cut to fit firmly in place between the windshield contour and the seatback headrest. The "through-the-windshield" camera was cantilevered so that it was located exactly on the vehicle center line and supported on a Bogen 3025 head for three degrees of freedom in aiming. An additional support for the rear of this camera was custom-fabricated in order to prevent jiggle when the vehicle was in motion. The other camera was simply screwed to the plywood sheet.

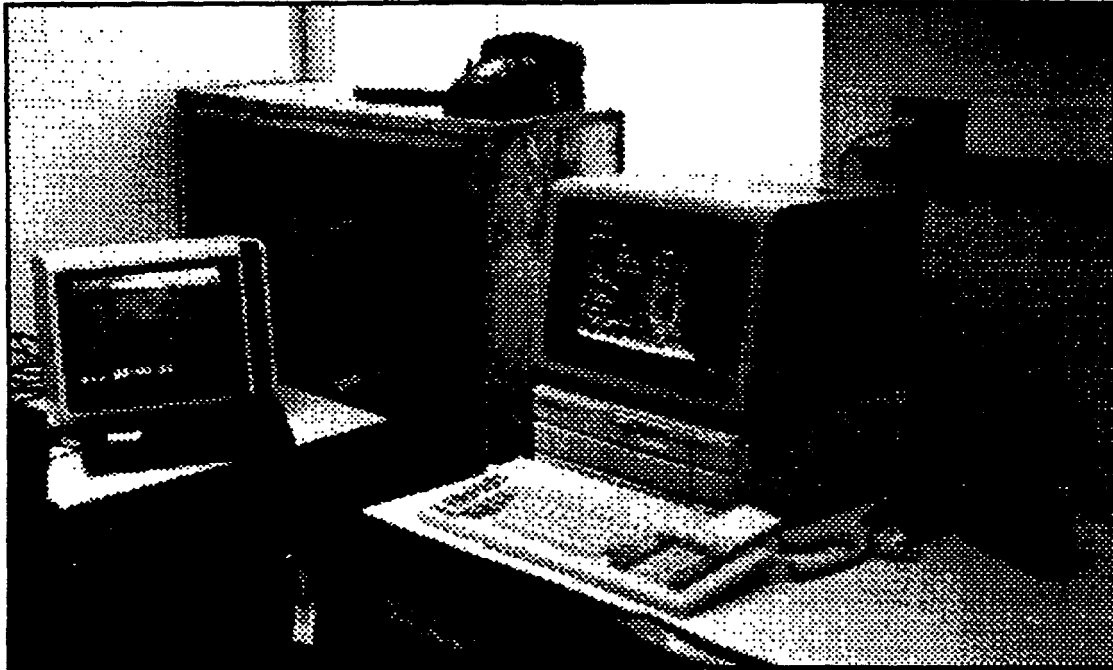


Fig. 3.2.1-1: Data Entry Equipment

The two camera outputs were combined in a Vidicraft SEG-200 special effects generator so that the “through-the-windshield” view occupied the upper two-thirds of the screen while the instrument view filled the lower portion. The SEG-200 was modified for 12 volt, DC operation.

A Panasonic AG-6400 portable VHS recorder was used in the test vehicle. The driver’s comments were recorded on one of its audio tracks while the beeper signals from the VRSS interface (described below) were on the other. The recording was monitored on a Panasonic CT-500V 5” unit.

All of the video gear was powered from the vehicle’s electrical system through a custom-built electrical filter and distribution box using standard XLR series connectors. Components lacking such connectors as supplied by the manufacturer were modified accordingly.

For playback and data entry, a Panasonic AG-1950 VCR was used, because of its editing features including several slow-motion speeds and frame-by frame stepping controlled by a “jog/shuttle” ring, which are essential to efficiency in the data entry process.

A Panasonic TR-120 computer display was used as a video monitor for playback. This monochrome unit was preferred over the usual color monitor because its higher resolution allowed slightly better accuracy in measuring the width of objects on the screen.

The data entry playback system along with the personal computer used for data entry are shown in Figure 3.2.1-I.

3.2.2 Digital Speedometer

The road speed of the test vehicle was measured by a Micron Surveyor. This miniature instrument senses vehicle speed by means of a pick-up coil mounted near one wheel together with a pair of magnets attached to that wheel. Once calibrated to the left-front tire of the test vehicle, its accuracy was found to be within plus or minus 0.5 miles per hour when compared with a Nucleus Corp. fifth wheel which had recently been factory calibrated to NBS standards.

3.2.3 Police Radar Gun

Speed of approach to target vehicles was measured by two independent techniques. In the first it was calculated by dividing the difference between successive range measurements from the optical system by the elapsed time. There is an expected error of several percent in these range measurements. The elapsed time between range measurements is subject to quantization error for standard video which is 0.033 seconds. That is, even though the stopwatch shows time in increments of 0.01 seconds, only every third or fourth reading is available on the video tape because each frame takes 0.033 seconds. Since many of the measurements were only a fraction of a second apart, the quantization error can introduce significant additional discrepancy.

Therefore a second technique to measure target closing speed was devised using a First American Research K-band police radar gun. Because these guns are designed to blank their displays when the detected speed is less than 1.7 mph, the normal filters were replaced with those from an X-band gun which lowers the cutoff speed to 5 mph. Thus modified, the gun was installed in a cutout in the plywood panel along with the other instruments.

Due to the behavior of the filters and automatic gain control circuits in a radar gun, the speed displayed varies with conditions. In general the filters are designed such that when multiple targets are present, the highest speed differential will be read out. However a very strong signal from a nearby target can override one from a more distant target even if the latter has a higher differential speed. In practice, this means that a radar gun mounted in moving vehicle will usually show that vehicle's road speed if

there are no other vehicles within a few hundred feet. If other vehicles are being overtaken, the speed displayed will usually be the differential with respect to the slowest of them. However, if the target is within three car lengths and especially if it is a large truck, it may mask the beam so that the speed displayed will be correct even if there are slower vehicles in adjacent lanes. Furthermore the output is smoothed by filter with a time constant on the order of one second. Hence if the closing rate is declining rapidly, the readout will overstate the true rate at a given instant and conversely. Finally, the display is often blank because the speed differential with a nearby target is less than 5 mph.

In light of the problems with both methods to closing rate measurements, data from both methods were recorded. A set of decision rules was incorporated in the data analysis process (described below) to determine which measurement would be used in each of the hundreds of approaches to target vehicles.

3.2.4 VRSS Interface

Under the terms of the agreement between NHTSA and VRSS, no modifications of the VRSS device were permitted. This clause prohibited normal direct electrical connections of VRSS outputs to recording instrumentation. Hence the VRSS dashboard display unit was placed inside a custom-built interface which contained four phototransistors to monitor the status of each of the LED's and a microphone and tone-detector circuit to monitor beeping. The interface was also connected to the brake light circuit so that brake applications could be monitored. The outputs of these circuits were fed to two repeater displays. One repeater was mounted on the dashboard for convenient viewing by the driver. The other was placed before the instrumentation camera, as noted above.

3.3 Data Collection

All data collection was performed on interstate highways with a least three travel lanes in each direction. Light to moderate traffic densities allowed collection of the greatest volume of data per unit time and also permitted higher closing speeds.

At the beginning of each data recording session, date, location and direction of travel were recorded on the tape.

The test vehicle was driven at speeds of five to twenty-five miles per hour faster than the target vehicles but within the normal speed envelope of the road. As each target was passed, its make, nameplate and size class were spoken into the driver's

microphone and recorded by the VCR. A comment on the adequacy of the warning provided by the VRSS was also made.

Several hours' of video tape, recording approaches to more than 350 vehicles, were accumulated. By reviewing this tape in slow motion or freeze-frame one could easily determine precisely how much warning time the VRSS unit provided prior to the commencement of a braking or lane-change maneuver,

3.4 Data Entry

The data-entry clerk was instructed to read time, test-vehicle speed, closing speed (if available from the radar gun), status of various indicators, target-width and driver-response data from several frames in the approach to each target vehicle. The first frame read was that in which the yellow "ALERT" LED on the VRSS switched on. The second frame corresponded to the onset of illumination of the red "WARNING" LED. The third was associated with the "DANGER" LED. Since the "WARNING" and "DANGER" LED's came on simultaneously more often than not, these two lines were often combined. The fourth (or third) line marked the start of beeping. The last line of data for each case was taken at the moment either braking or lane-change was initiated. The former was signalled by an LED on the repeater display while the latter had to be judged by the data-entry clerk based on the "through-the-windshield" view. Some cases did not include one or more of the warning lines because the VRSS failed to generate them before evasive action was necessary.

As noted in the statement of objectives, only the audible warning was counted in scoring performance of the VRSS. The other levels of warning were used only as convenient reference points for range measurements. The full data set remains available to other analysts who may wish to score performance on the basis of the visual warnings.

Figure 3.4.1 shows an example of a completed data entry screen for one line using a relational database software package called "Rbase System V." Four lines of input data associated with the approach to one vehicle appear in Figure 3.4.2,

Edit Save Add new Delete Reset Previous Next Quit

NEW OBSERVATION : Y

MAKE	MODEL	SIZE-CLASS
OLDSMOBILE	CUTLASS	->3
TIME	DISTANCE	
HR MIN SEC	TRAVELLED(FEET)	
0 : 0 : 22.8	0.	
VEHICLE SPEED(MPH)	CLOSING SPEED(MPH)	
68.	7.	
MEASURED WIDTH(mm): 56.		
ACTIVE WARNINGS(Y/N)		
ACQUIRE 1 2 3 BEEPER		
N Y N N N		
ACTION TAKEN(Y/N)		
BRAKE EVASIVE MANEUVER		
N N		
ADEQUATE WARNING GIVEN : -<		

*** PLEASE ENTER ALL INFORMATION ***
 VERIFY ALL DATA

SIZE CLASS	VEHICLE
1: Sub-Compact	CAR
2: Compact	CAR
3: Intermediate	CAR
4: Full-Size	CAR
5: Small	PICK-UP
6: Full-Size	PICK-UP
7: Mini	VAN
8: Full-Size	VAN
9: Large	TRUCK
ADEQUATE WARNING	
Y	:: Adequate Warning
N	:: Inadequate Warning
-	:: No Comment

[ESC] Done [F2] Clear field [Shift-F2] Clear to end [Shift-F10] More
 Form: ADDOBS Table: OBSERV Field: NEW_CASE Page: 1

Notes: For the entry labelled "ACQUIRE," a "Y" (yes) designates a new case, while an "N" (no) indicates a continuation line. "1," "2" and "3" refer to the LED's on the VRSS display labelled "Alert," "Warning" and "Danger" respectively.

Figure 3.4-1: Data Entry Screen.

NEW CASE	MAKE	MODEL	SIZE	HR	MIN	SEC	ASPEED	CSPEED	TRWIDTH	ACQUIRE	LIGHT_1	LIGHT_2	LIGHT_3	BEEPER	BRAKE	EVASIVE
Y	1	OLDSMOBILE	CUTLASS	3	0	0	22.8	68.	7.	56	N	Y	N	N	N	N
N	1	OLDSMOBILE	CUTLASS	3	0	0	23.14	68.	7.	58	N	Y	Y	Y	N	N
N	1	OLDSMOBILE	CUTLASS	3	0	0	24.1	67.1	7.	66	N	Y	Y	Y	Y	N
N	1	OLDSMOBILE	CUTLASS	3	0	0	26.27	66.9	5.	84	N	Y	Y	Y	Y	N

Figure 3.4-2 Input Data for One Case

After the initial data entry was completed, a listing of the specific make-model passenger cars in the sample was generated. The widths for most of these vehicles were determined from charts published in AUTOMOTIVE NEWS’ “1986 Model Passenger-Car Specifications,” dated November 1 I, 1985. For the vast majority of make-models, these widths have not changed appreciably in the last few years, Hence, the same numbers were used for all model years. These width data were then inserted into the data base. There were 69 target vehicles, mostly trucks, for which width data could not be found, usually because the vehicle or trailer was not identified as to make/model on the tape. For these, averages for the size class were used:

Subcompact	66.1 inches
Compact	69.1
Intermediate	70.6
Full-Size	75.4
Small Pickup	70.0
Large Pickup	76.0
Small Van	70.0
Large Van	75.0
Heavy Truck	96.0

3.5 Data Analysis

These frame data together with data on the actual widths of various vehicles make it possible to calculate the distance to target for any particular frame using the range equation discussed in section 3.2.1. When target width is known exactly, the range error can be held to 3 percent or less over the distances of interest. When specific make-model designation is not available, additional errors of about 5% may be introduced by using size-class averages rather than actual widths.

The first step in preparing the data for analysis was to determine which radar-speed-gun readings and which optical ranges were invalid. Approach speeds were calculated from successive range measurements by dividing the difference by the elapsed time. These rates were then compared with the corresponding rates from the radar gun. Whenever the radar rate exceeded the optical rate by more than 20 %, it was considered invalid because the radar gun was probably reading closing rate against some vehicle travelling slower than the target. Disregarding these cases as well as those in which the speed gun had blanked, the average closing rate calculated by the optical method was found to exceed that from the speed gun by only 10.6%. This discrepancy is well within the expected error range given the inherent limits of the video/optical method,

the lack of actual width data for many of the targets and the dynamic errors of the radar gun.

For all subsequent data analysis, the following rules were applied:

1. Closing rates were taken from the speed-gun for all cases in which they were available, unless they exceeded 25 mph or exceeded the optical rates by more than 20%. In the latter case, the optical rate was used.
2. Optical rates were used where speed-gun data were unavailable so long as their values fell between 5 and 25 mph. If the optical rates appeared suspicious, i.e., values greater than 25 mph or less than 5 mph, the case was excluded from subsequent analysis.

Figure 3.5-1 shows examples of several cases selected because of invalid data. In Figure 3.5-2 the invalid or suspicious calculated rates have been zeroed.

Out of 355 original cases, 349 remained after the unexpected lane change cases had been excluded. These six cases were excluded because either the target vehicle changed lanes or the test vehicle was forced to change lanes because of other traffic during an approach. 237 cases had valid rate data (as indicated by a non-zero value in the column labelled "CLOSE" in the same line as the first "BEEP" "Y" occurs).

Following the exclusion of doubtful cases and using only the closing rate selected by the rules above, a calculation of the warning time provided by the beeper was performed for each case. That is, the distance to the target vehicle at the instant the beeper sounded was divided by the closing rate at that time to determine the number of seconds to impact had that closing rate been maintained. There were 81 valid cases in which the beeper never sounded, which were also carried into the subsequent analysis.

Appendix One contains the entire data set including the calculated ranges, rates, and warning times.

CASE	MAKE	MODEL	ASPEED	CSPEED	BEEPER	BRAKE	EVASIVE	OPT_RATE	RAD_RATE	RATE_RAT
1	OLDSMOBILE	CUTLASS	68.	7.	N	N	N	4.273112	10.26667	0.416212
16	-0-	-0-	75.4	10.	N	N	N	7.202662	14.66667	0.491091
20	NISSAN	MAXIMA	50.9	14.	N	N	N	-0.93588	16.86667	-0.05549
20	NISSAN	MAXIMA	50.5	4.	N	N	N	0.	13.2	0.
21	-0-	TRUCK	66.6	6.	N	N	N	0.	10.26667	0.
36	-0-	TRUCK	74.1	17.	N	N	N	30.2375	39.6	0.763573
39	VOLKSWAGON	RABBIT	74.1	11.	N	N	N	-15.2769	16.13333	-0.94691
44	-0-	-0-	72.1	11.	N	N	N	0.	16.13333	0.
48	CHEVROLET	PICK-UP	74.7	16.	N	N	N	0.	23.46667	0.
49	PONTIAC	BONNEVILLE	74.7	13.	N	N	N	0.	14.66667	0.
51	DATSUN	-0-	74.3	8.	N	N	N	0.	11.	0.
56	OLDSMOBILE	-0-	75.4	7.	N	N	N	-0-	10.26667	-0-
57	TOYOTA	CELICA	75.	13.	N	N	N	0.	19.06667	0.

Figure 3.5-1: Examples of Cases with Invalid Rate Data

CASE	MAKE	MODEL	ASPEED	CSPEED	BEEPER	BRAKE	EVASIVE	OPT_RATE	RAD_RATE	RATE_RAT	CLOSE
1	OLDSMOBILE	CUTLASS	68.	7.	N	N	N	4.273112	10.26667	0.416212	0.
16	-0-	-0-	75.4	10.	N	N	N	7.202662	14.66667	0.491091	0.
20	NISSAN	MAXIMA	50.9	14.	N	N	N	-0.93588	16.86667	-0.05549	0.
20	NISSAN	MAXIMA	50.5	4.	N	N	N	0.	13.2	0.	0.
21	-0-	TRUCK	66.6	6.	N	N	N	0.	10.26667	0.	0.
36	-0-	TRUCK	74.1	17.	N	N	N	30.2375	39.6	0.763573	0.
39	VOLKSWAGON	RABBIT	74.1	11.	N	N	N	-15.2769	16.13333	-0.94691	0.
44	-0-	-0-	72.1	11.	N	N	N	0.	16.13333	0.	0.
48	CHEVROLET	PICK-UP	74.7	16.	N	N	N	0.	23.46667	0.	0.
49	PONTIAC	BONNEVILLE	74.7	13.	N	N	N	0.	14.66667	0.	0.
51	DATSUN	-0-	74.3	8.	N	N	N	0.	11.	0.	0.
56	OLDSMOBILE	-0-	75.4	7.	N	N	N	-0-	10.26667	-0-	0.
57	TOYOTA	CELICA	75.	13.	N	N	N	0.	19.06667	0.	0.

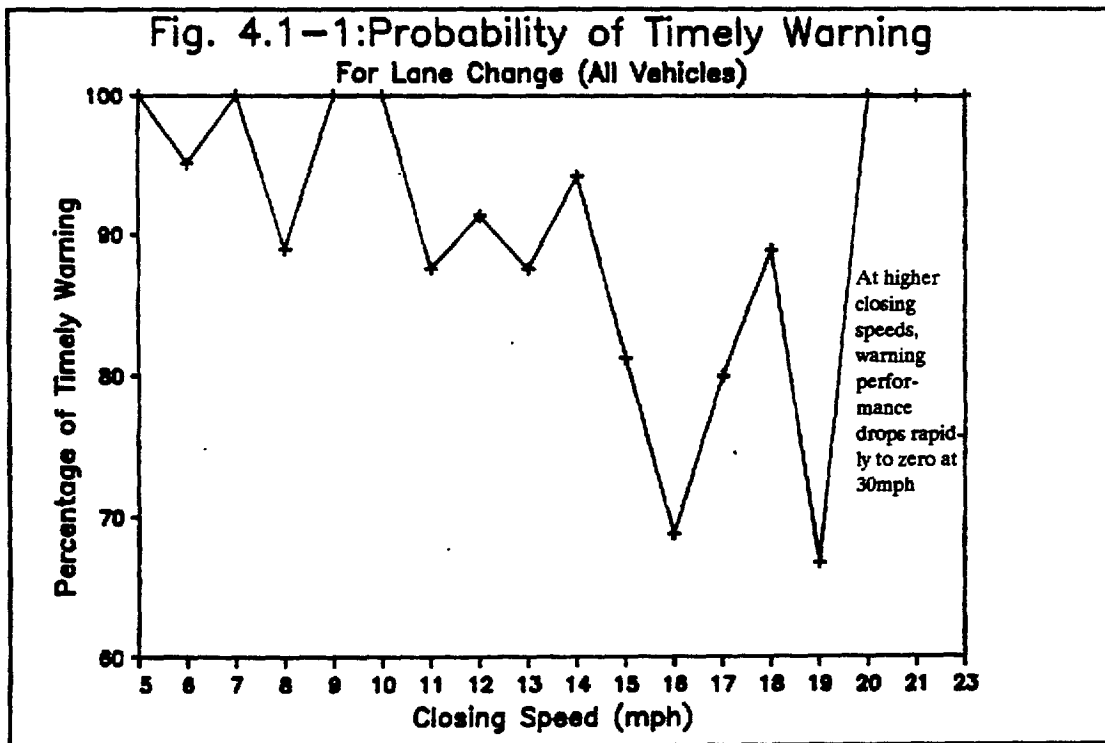
Figure 3.5-2: Examples with Doubtful Rates Zeroed

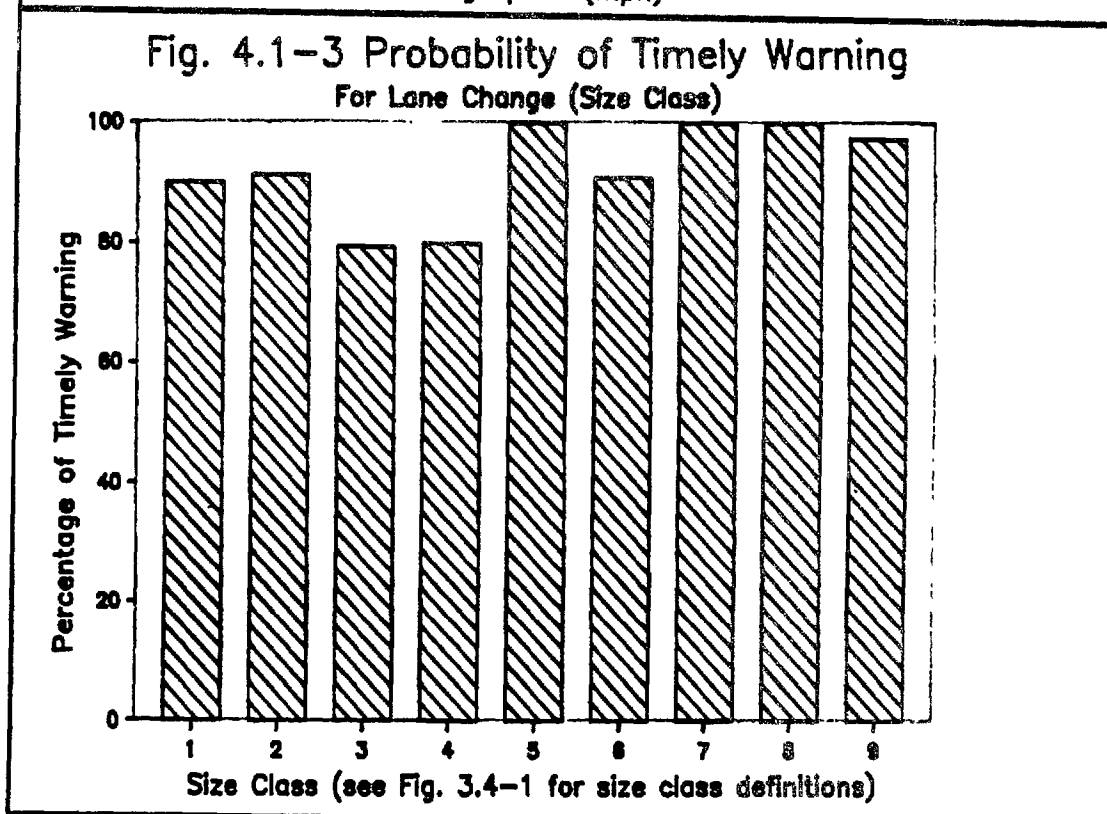
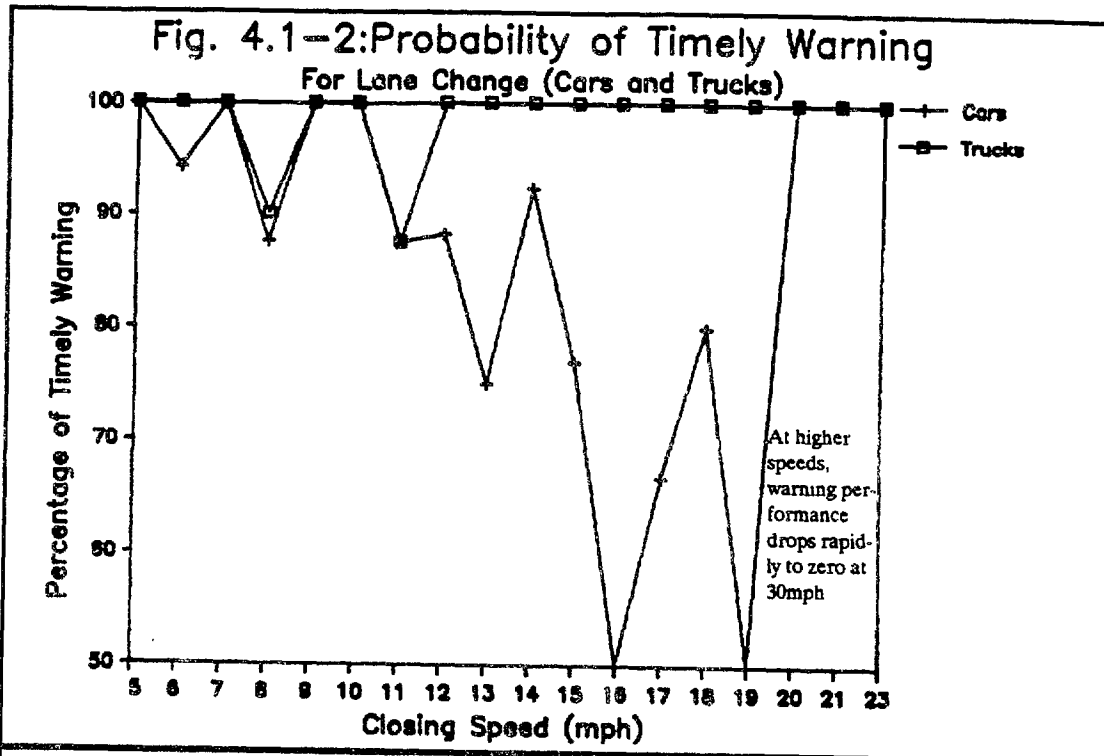
4.0 RESULTS

4.1 Probability of Warning Versus Closing Speed

The simplest and most basic measure of VRSS performance is whether or not it provides warning before evasive action must be taken. Figure 4.1-1 is a graph of the percentage of cases in which audible warning was given prior to the onset of evasive action for each one mile-per-hour increment in closing speed. It is drawn directly from the cases in Appendix One. In calculating the probabilities, all of the valid cases in each one-mile-per-hour increment of closing speed were counted. If the beeper sounded prior to the beginning of braking or evasive lane change, the case was counted as timely warning. It is apparent that under the conditions prevailing when the data were taken (dry road, attentive driver, light to moderate traffic), the probability of timely warning was fairly high for low closing speeds but declined substantially as closing rate increased above ten miles per hour.

Figure 4.1-2 shows the same probability curves but with passenger cars separated from trucks. Because their large, vertical, planar surfaces are much better radar reflectors



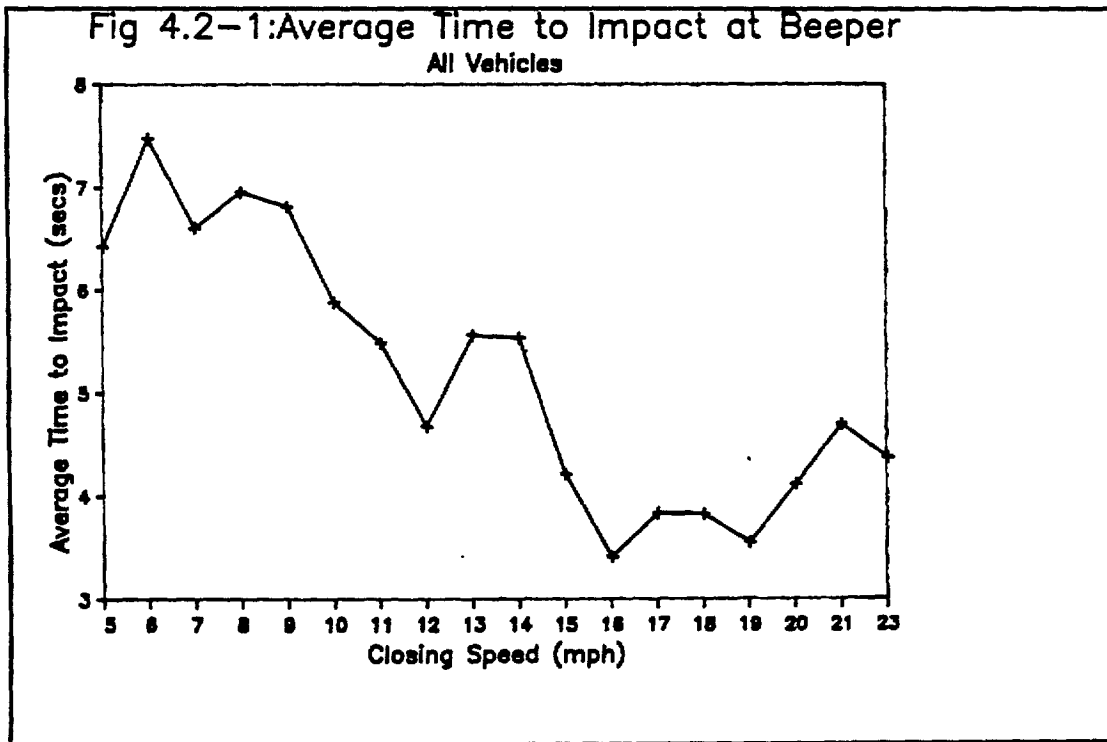


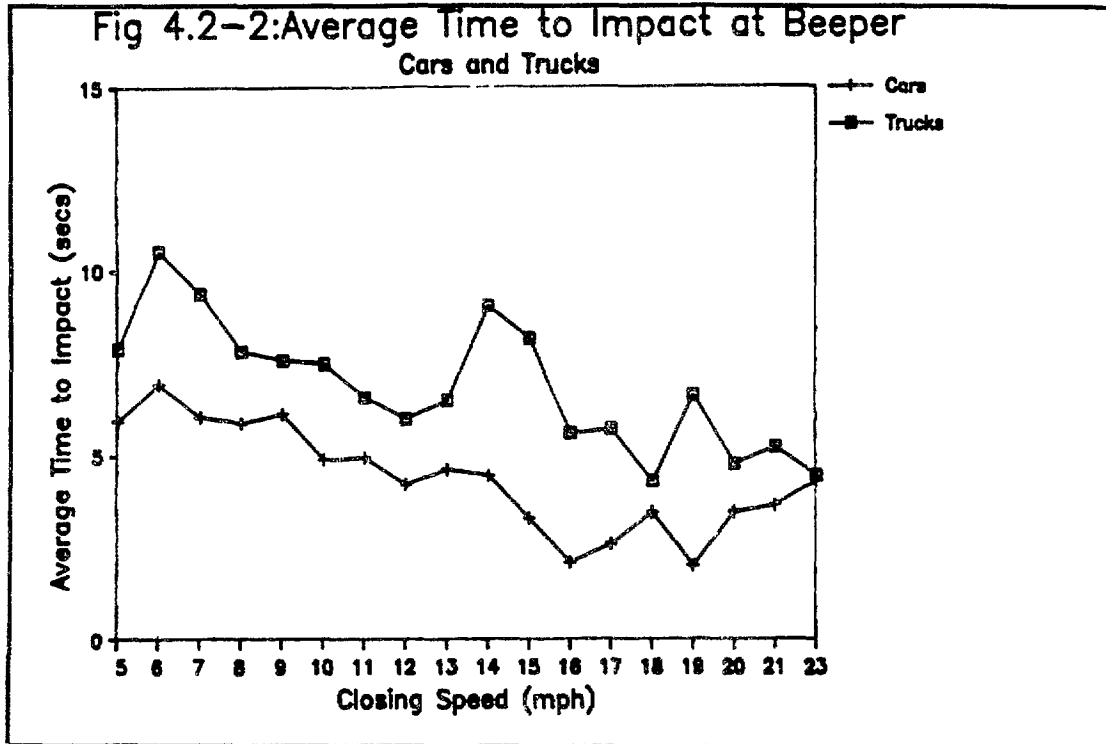
than the smaller, mostly convex surfaces of passenger cars, trucks provide a much greater likelihood of good warning. Warning probabilities were also broken down by size-class in Figure 4.1-3. Summed over all closing speeds the variations among passenger cars were unrelated to size, indicating that the specific shape of reflecting surfaces, especially the taillights, is much more important than size per se.

4.2 Seconds to Impact Versus Closing Speed

The probabilities shown in Section 4.1 are affected by both VRSS performance and the judgement of the test driver, the author, as to when it is necessary to begin evasive action in a particular closing situation. That is, the greater the risk of actual collision the driver is willing to take, the higher the chance the VRSS will sound a warning before the evasive action begins. In order to eliminate the latter variable, in this section an additional performance measure, "seconds to impact," has been calculated. This time is simply the range at the instant the beeper starts divided by the closing rate at that moment. Figures 4.2-1 and 4.2-2 show the results.

From these figures, it is evident that the VRSS's circuitry is designed to increase its sensitivity as vehicle speed increases. Otherwise "seconds to impact" would decrease in inverse proportion. The declines shown in the figures are caused by failures to detect some passenger cars at higher speeds. If only the targets which were detected had been





plotted in these figures, the curves would lie essentially flat out to nearly 30 mph at about six seconds warning time. Above that speed, the warning time rapidly falls to zero because of the filters incorporated to eliminate responses to stationary objects.

4.3 Probability of Warning in Time to Brake Versus Closing Speed

All testing for this evaluation was conducted on dry roads by an unimpaired driver. Traffic was mostly light to moderate, with somewhat higher densities during the last of the six hours of video taping. Under these conditions a driver response time on the order of one second and a braking coefficient of about 0.5 g are reasonable assumptions. Collisions with target vehicles were avoided through lane-changes rather than braking in the vast majority of approaches. Had braking been the only allowable maneuver, many of the approaches in which the VRSS provided an adequate warning would never have been made at closing speeds above 10 mph.

If braking is the only available means to avoid collision with a vehicle being overtaken, the minimum distance at which the warning must occur depends upon the initial speeds of the vehicles, braking rates and reaction time. Some of the possibilities are described in the following equations:

For the case in which the target vehicle maintains a constant speed:

$$D_m = ((V_v - V_t) * Tr) + (V_v - V_t)^2 / 2a \quad (\text{equation 1})$$

where

D_m = distance minimum for warning

v_v = velocity of VRSS car

Tr = reaction time for driver and braking system

V_t = velocity of target vehicle

a = braking deceleration (typically about .5 g
for dry pavement; about .3 g for wet
pavement; and about .1 g for ice)

In this case the leading vehicle is not slowing down and the required distance minimums are not as large as in the other cases described below. For example at a closing speed of 20 feet per second, slightly less than 14 mph, the minimum is only 32.5 feet. The VRSS can be relied upon for timely warnings in this situation.

At the opposite extreme, one might assume that warning did not occur until the instant the leading vehicle began braking. For this case the minimum distance is:

$$D_m = (V_v + Tr) + ((V_v - V_s) / 2a) \quad (\text{equation 2})$$

This distance is simply the sum of the distance travelled during the reaction time of the following car's driver plus the difference in stopping distances caused by the difference in initial speeds. Table 4.3-1 shows the calculated minimum warning distances for various combinations of vehicle speeds and assumed reaction times and braking coefficients.

For comparison with the calculated minimum warning-distance data, Figure 4.3-1 shows the average distance at which audible warnings were produced by the VRSS versus road speed of the test vehicle. (This distance is also affected by closing speed, but showing this relationship as a function of two variables would require software capable of generating a pseudo-three-dimensional plot, which was unavailable for this project.) It was derived from only those cases in which audible warnings occurred.

It is obvious that for most combinations of closing speeds and road speeds shown in Table 4.3-1, the required warning distances are greater than the detection range of the VRSS. Fortunately, the situation in which warning does not occur until the leading vehicle begins braking is rarely encountered except when the two vehicles are travel-

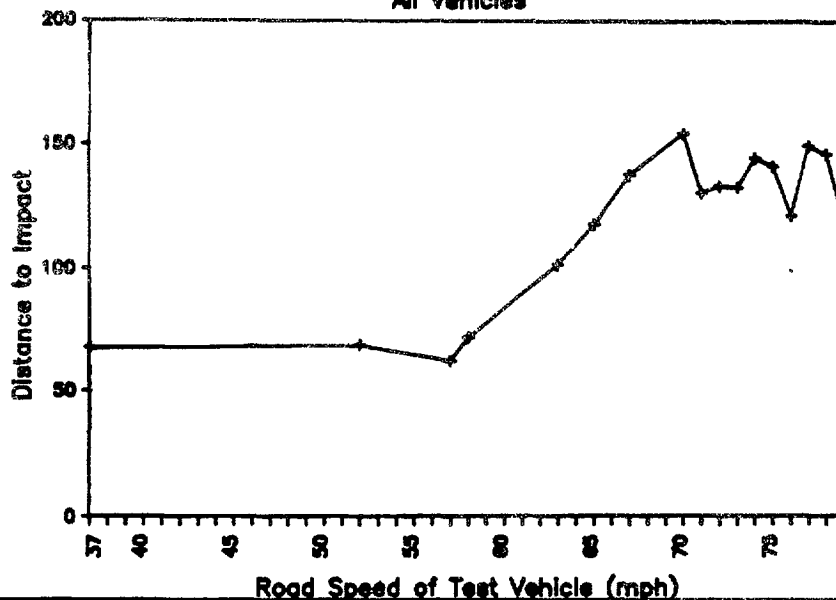
CLOSING SPEED	ROAD SPEED OF TEST VEHICLE (DRY, 1.0 SEC REACTION TIME)												
	25	30	35	40	45	50	55	60	65	70	75	80	85
0	37	44	51	59	66	73	81	88	95	103	110	117	125
5	52	62	73	84	95	105	116	127	137	148	159	169	180
10	64	78	92	106	120	134	148	162	176	190	204	218	232
15	72	89	107	124	142	159	176	194	211	229	246	264	281
20	77	98	119	139	160	181	202	222	243	264	285	306	326
25	79	103	127	151	175	199	224	248	272	296	320	344	368

CLOSING SPEED	ROAD SPEED OF TEST VEHICLE (WET, 1.0 SEC REACTION TIME)												
	25	30	35	40	45	50	55	60	65	70	75	80	85
0	37	44	51	59	66	73	81	88	95	103	110	117	125
5	62	75	88	101	114	127	139	152	165	178	191	204	217
10	81	100	119	137	156	174	193	211	230	248	267	285	304
15	95	120	144	168	192	216	240	264	289	313	337	361	385
20	104	134	163	193	223	253	282	312	342	372	401	431	461
25	107	142	177	213	248	283	319	354	389	425	460	495	531

CLOSING SPEED	ROAD SPEED OF TEST VEHICLE (ICE, 2.0 SEC REACTION TIME)												
	25	30	35	40	45	50	55	60	65	70	75	80	85
0	73	88	103	117	132	147	161	176	191	205	220	235	249
5	149	180	212	243	275	306	338	369	401	432	464	495	527
10	208	256	304	353	401	449	497	546	594	642	691	739	787
15	250	315	380	445	510	575	640	705	770	836	901	966	1031
20	275	357	439	521	603	684	766	848	930	1012	1094	1176	1258
25	283	382	481	579	678	777	876	974	1073	1172	1270	1369	1468

Table 4.3-1: Distances (feet) Required for Equation 2

Fig. 4.3-1: Average Feet to Impact at Beeper
All Vehicles



Note:
These data represent samples for all closing speeds.

ling at about the same speed. For this condition, shown in the top line of each section of the table, the warning range of the VRSS is usually adequate.

The more common case in practice is one in which the VRSS-equipped vehicle is overtaking the leading vehicle even before the latter begins braking. At highway speeds, the VRSS is designed to generate audible warnings even for very low closing speeds if the distance is short enough. Thus if $V_v - V_t > 0$, the warning begins as soon as the target is within a certain range and usually before the leading vehicle begins braking. Hence this case is something of a hybrid between the two equations shown above. The difference in braking distances is given by $(V_v^2 - V_t^2)/2a$, but the reaction time occurs while the leading vehicle is still travelling at its initial velocity, V_t . Therefore, the additional distance required to compensate for reaction time is given by $(V_v - V_t) * Tr$ and the total warning distance is:

$$D_m = ((V_v - V_t) * Tr) + (V_v^2 - V_t^2) / 2a \quad \text{(equation 3)}$$

Table 4.3-2 shows the warning distances required under this assumption. To score VRSS performance on how well it provides timely warnings for this case, Table 4.3-3 displays counts of how many approaches to target vehicles were recorded for various combinations of road speed and closing speed and what percentages of each of these produced warnings at distances greater than those specified in Table 4.3-2 for dry pave-

CLOSING SPEED	ROAD SPEED OF TEST VEHICLE (DRY, 1.0 SEC REACTION TIME)												
	25	30	35	40	45	50	55	60	65	70	75	80	85
0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	22	26	29	33	36	39	43	46	49	53	56	59	63
10	42	48	55	62	68	75	82	89	95	102	109	116	122
15	57	67	77	88	98	108	118	128	138	148	158	168	178
20	70	83	97	110	123	137	150	164	177	191	204	218	231
25	79	95	112	129	146	163	180	196	213	230	247	264	280

CLOSING SPEED	ROAD SPEED OF TEST VEHICLE (WET, 1.0 SEC REACTION TIME)												
	25	30	35	40	45	50	55	60	65	70	75	80	85
0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	33	38	44	49	55	61	66	72	77	83	89	94	100
10	59	71	82	93	104	116	127	138	149	160	172	183	194
15	81	98	114	131	148	165	182	198	215	232	249	266	282
20	97	119	141	164	186	209	231	253	276	298	321	343	365
25	107	135	163	191	219	247	275	303	331	359	387	415	443

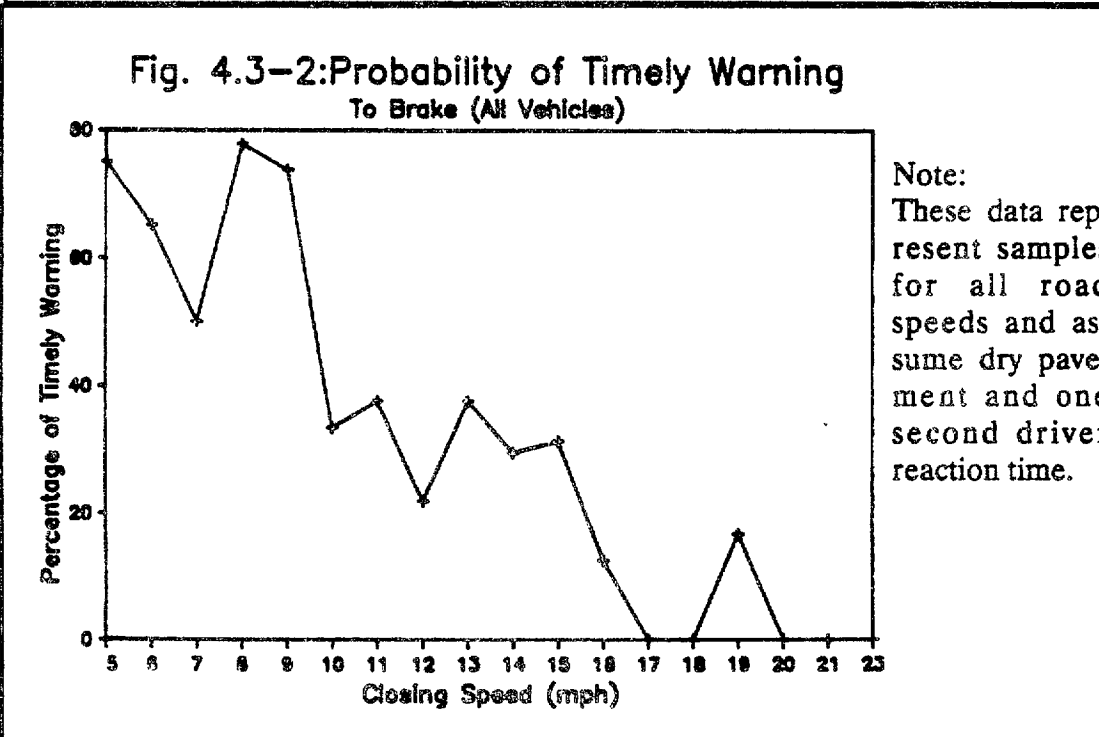
CLOSING SPEED	ROAD SPEED OF TEST VEHICLE (ICE, 2.0 SEC REACTION TIME)												
	25	30	35	40	45	50	55	60	65	70	75	80	85
0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	90	107	124	141	158	174	191	208	225	242	258	275	292
10	164	197	231	265	298	332	365	399	433	466	500	534	567
15	220	271	321	372	422	473	523	573	624	674	725	775	825
20	260	328	395	462	529	596	664	731	798	865	933	1000	1067
25	283	367	451	535	620	704	788	872	956	1040	1124	1208	1292

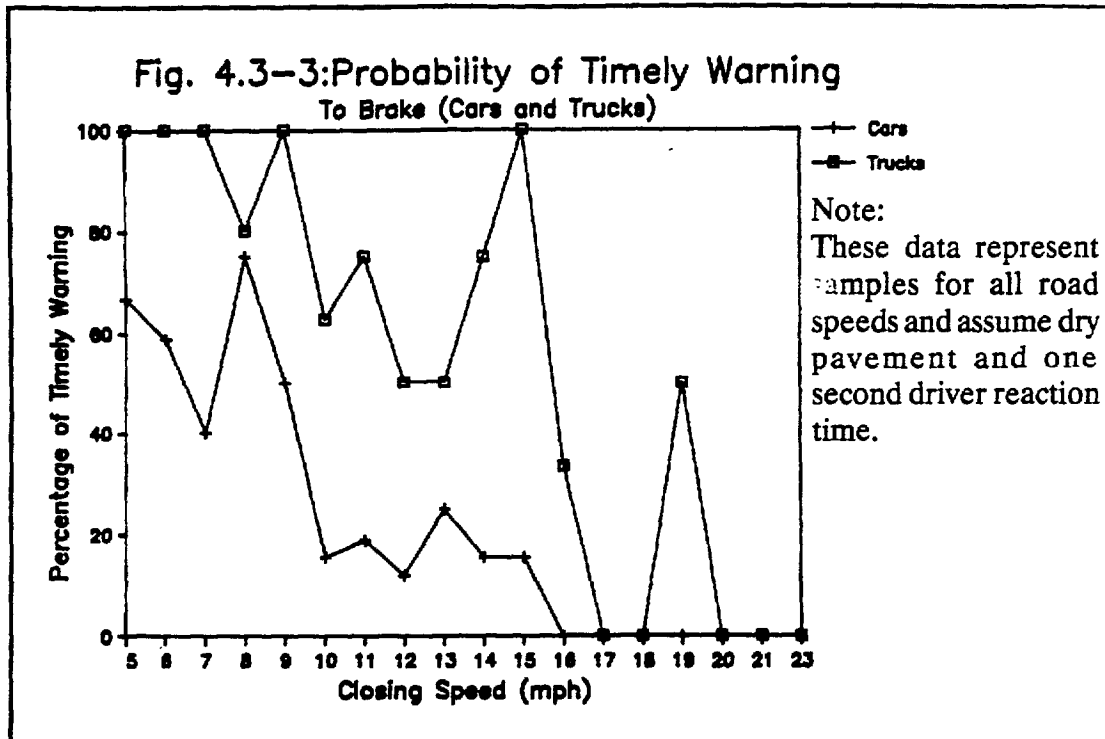
Table 4.3-2: Distances (feet) Required for Equation 3

ment and one-second reaction time. Since most of the data were gathered with test vehicle speeds above 60 mph, there are relatively few data points for the lower speeds and hence the statistical uncertainty about the performance of the VRSS is much greater at such speeds.

	CLOSING SPEED				
	5	10	15	20	25
40	100% (01)				
45					
50	50% (02)				
55	100% (01)				
60	100% (01)				
65	25% (04)	54% (13)	100% (01)		
70	56% (09)	39% (28)	6% (17)	0% (03)	
75	68% (19)	49% (55)	27% (45)	6% (17)	0% (02)
80	100% (01)	29% (07)	14% (07)	0% (04)	
total	61% (36)	47% (105)	26% (70)	4% (24)	0% (02)

Table 4.3-3: Percentage of Vehicles Which Produced an Adequate Warning on Dry Pavement with a One Second Reaction Time. The total number of vehicles for each combination of speeds is given in parenthesis.





From the above, one may readily observe that the VRSS usually generates warnings in time to avoid collision by braking for lower speeds so long as driving conditions are favorable and the driver has unimpaired reaction time. At highway cruising speeds of 60 mph and higher however, the probability of warning in time for braking falls to about 60% for five mph closing speeds. For 10 mph closing speeds the chance of warning is slightly less than half and drops further for still higher closing speeds. Figures 4.3-2 and 4.3-3 show the probabilities graphically summed over all road speeds.

If wet or icy conditions are assumed or if the driver is impaired, the required warning distances when the leading vehicle is also braking exceed the capabilities of the VRSS for all but the lowest speeds and closing rates. Table 4.3-4 repeats the calculations shown in Table 4.3-3, but with a braking coefficient of 0.3 g.

		CLOSING SPEED				
		5	10	15	20	25
ROAD SPEED	40		0% (01)			
	45					
	50	0% (02)				
	55	0% (01)				
	60		0% (01)			
	65	0% (04)	23% (13)	0% (01)		
	70	22% (09)	11% (28)	6% (17)	0% (03)	
	75	21% (19)	9% (55)	0% (45)	0% (17)	0% (02)
	80	0% (01)	0% (07)	0% (07)	0% (04)	
totl		17% (36)	10% (105)	1% (70)	0% (24)	0% (02)

Table 4.3-4: Percentage of Vehicles Which Produced an Adequate Warning on Wet Pavement with a Reaction Time of One Second. The total number of vehicles for each combination of speeds is given in parenthesis.

4.4 Problem Targets

During the Phase I testing it became obvious to the drivers that instances of failure to sound the beeper before evasive action was taken were not randomly distributed across the population of target vehicles. Certain makes and models repeatedly failed to produce warnings. In discussions with the chief designer of the VRSS, William Goodson, it was learned that the taillight reflectors are responsible for most of the energy reflected from passenger cars at 24 GHz. Although most cars have taillight reflectors which are coincidentally well shaped for this purpose, a few do not. In particular, taillights which are unusually small (e.g., early Volkswagen Beetles) or which have a narrow vertical configuration (e.g. Cadillacs) do not return much signal. Large, flat vertical surfaces, such as are found on all trucks, are also good reflectors, so that the shape of their taillights is immaterial.

Table 4.4-1 lists the specific make-model vehicles which did not produce audible warning prior to the onset of evasive action. Particularly prominent in this listing are Cadillacs, because of their narrow vertical taillights, and Oldsmobile Cutlasses, the taillights of which have a square overall shape, but which are composed of two vertically oriented reflectors side by side. Subaru's also appear in numbers disproportionate to their fleet size, but this may simply be a fluke related to small sample size. The taillight designs favored by most European and Japanese manufacturers, which have separate reflectors and lenses for brake, turn signal and back-up lights, are also good radar reflectors. As a result, these cars make up a much smaller proportion of the cars which did not provide timely warning than they do of the sample as a whole.

MAKE	MODEL	OCCURENCES
AMC	SPIRIT	1
BUICK	CENTURY	1
BUICK	ELECTRA	1
BUICK	LASABRE	1
BUICK	REGAL	2
BUICK	SKYHAWK	1
BUICK	-0-	3
CADILLAC	COUP DEVILLE	1
CADILLAC	DEVILLE	1
CADILLAC	FLEETWOOD	1
CADILLAC	-0-	3
CHEVROLET	CAMERO	2
CHEVROLET	CAPRICE	2
CHEVROLET	CELEBRITY	1
CHEVROLET	CHEVETTE	2
CHEVROLET	IMPALA	2
CHRYSLER	NEW YORKER	2
DATSUN	210	1
DATSUN	-0-	1
DODGE	ARIES	1
DODGE	DART	1
FORD	ESCORT	1
FORD	ESCORT WAGON	1
FORD	FAIRMONT	1
FORD	LTD	1
FORD	TAURUS	1
FORD	TEMPO	1
FORD	THUNDERBIRD	1
FORD	-0-	2
HONDA	ACCORD	2
LINCOLN	TOWN CAR	1
MAZDA	626	1
MAZDA	GLC	1
MERCURY	CAPRI	1
MERCURY	MARQUI	1
MERCURY	ZEPHYR	1
MERCURY	-0-	1
MG	MG	1
NISSAN	SENTRA	1
OLDSMOBILE	CUTLASS	7
OLDSMOBILE	CUTLASS SUPR	2
OLDSMOBILE	-0-	6
PLYMOUTH	COLT	1
PLYMOUTH	FURY	1
PLYMOUTH	RELIANT	1
PLYMOUTH	-0-	1
PONTIAC	BONNEVILLE	2
PONTIAC	GRAND AM	1
PONTIAC	SUNBIRD	1
SUBARU	DL	1
SUBARU	GL	2
SUBARU	-0-	2
TOYOTA	CELICA	1
VOLKSWAGON	BETLE	1
VOLKSWAGON	RABBIT	1
-0-	TRUCK	2
-0-	-0-	3

Table 4.4-1 Listing of Target Vehicles
Which Produced No Warning

5.0 ERROR ANALYSIS

The results shown in the preceding chapter are subject to errors arising from several sources. Among these are the composition of the sample of vehicles encountered on the highway during the testing, random variation in vehicle and road alignment during the approaches and inaccuracies in the range and closing rate measurements. VRSS performance could also be influenced by the set-up adjustments made by the dealer at the time of installation, which are in turn affected by certain electrical characteristics of the car. Thus the performance of the unit tested may not be truly representative of all VRSS units. (However, a pretest by Mr. Goodson indicated that the operation of the unit was typical.) Each of these types of errors is discussed below. Though worth mentioning, these errors do not significantly affect any of the results or conclusions of this study.

5.1 Sample Composition

For an un-impaired driver on a dry road travelling 70 mph, the VRSS was able to generate audible warnings of impending collisions about two-thirds of the time for passenger cars and about 95% of the time for trucks for the sample of vehicles encountered. Inasmuch as there are no known data on the distribution of radar-reflection characteristics of the fleet, there is no way of knowing whether the sample is really representative of the fleet. It is quite possible that another similar-sized sample would have shown a fraction of poor-reflectors considerably larger or smaller.

5.2 Range Measurements

As noted in Section 2.1, the optical/video range measurement technique was subject to errors of a few percent at distances of 60 to 100' even when the width of the target was known exactly. Additional errors on the order of five percent may have been introduced for about a quarter of the vehicles in the sample by the use of class-average widths.

5.3 Closing Rate

Closing rate data calculated from successive range measurements are subject to error not only from the range data, but also from the time quantization error (0.03 seconds) and from the fact that closing rate at the second range measurement may not be the same as the average over the period of time between range measurements. That is, the closing rate calculated from two successive range measurements must necessarily represent the average between the two corresponding points in time, which is not neces-

sarily equal to the closing rate at the second point. For approaches in which the test vehicle was slowing or the target accelerating, this calculation technique tends to overstate the true closing rate. Thus the “seconds to impact at warning” may be understated for such cases. If the test vehicle accelerated or the target slowed the converse would be true. While the errors in individual rate measurements could often exceed 20%, they are randomly distributed and do not significantly affect results or conclusions.

The closing rate reading from the radar gun was unavailable if that rate was below 5 mph or if a slower vehicle in an adjacent lane reflected a stronger signal than the target. Furthermore, the speed-gun’s tune-constant resulted in additional error if the closing rate was not constant. Since lane-changes rather than braking were the normal evasive maneuver, these errors have been kept to a minimum. Nonetheless the errors of as much as two miles per hour may be common in the closing rate data.

5.4 Set-up Adjustments

The VRSS is provided with two adjustments on its signal processor box which effectively control its sensitivity. These are concealed beneath a piece of adhesive tape marked “Removal of this tape voids warranty.” There is an additional adjustment inside the dashboard display which controls the time delay from the moment the “WARNING” LED lights until the beeper starts. All of these controls were left as set when the test vehicle was delivered to TSC. However, the performance of the VRSS on the various scales described in Section 4 could have been materially changed by re-adjustment of these controls.

During the installation process, the dealer is supposed to set these controls for as much sensitivity as possible without false alarms. If sensitivity is too high, various sources of electrical noise, e.g., alternator, ignition, accessory motors, can cause false triggering. The process for getting the best compromise between range and avoidance of false alarms relies on trial-and-error and judgment on the part of the installer. If the customer complains, controls are reset accordingly. Thus the performance of a given VRSS unit will depend to some extent upon the nature and magnitude of electrical noise generated by that vehicle. The installer’s preferences as between maximum warning time and minimization of superfluous warnings at stop lights may also influence performance. The settings used on the test vehicle were described as typical, but alternatives were not explored.

5.5 Target Alignment

At the usual working range for targets, 50 to 150 feet, the beam of the VRSS is only a few feet in diameter. Thus road curvature or changes in elevation can place a target partially or completely outside the beam. Furthermore, since Interstate highway lane widths are about twice those of passenger cars, it is easily possible for substantial lateral misalignment to occur even on a straight level road.

The VRSS will provide warning at the greatest distance when the target is centered in its beam. If the centerline of the target is displaced even three feet from the beam center, some reduction in warning distance seems to occur. If the misalignment reaches six feet (an alignment which could still produce a side-swipe), there may be no warning at all.

Examination of the video tape shows that a substantial proportion of the targets which produced no warning or insufficient warning from the VRSS were misaligned to some extent. Thus many of the vehicles listed in Table 4.4-1 as problem targets might not have appeared there had they been centered in the beam during the approach.

In conclusion, the VRSS will provided the greatest average warning distance on straight, level roads with narrow lanes. Had the test program been conducted on such roads, rather than the gently curving and sloping, wide-laned Interstates actually used, the fraction of vehicles not detected in time for safe evasive action might have been reduced by a factor of two or more. Conversely, had the testing been conducted on mountain roads the measured performance could have been much worse.

6.0 CONCLUSIONS

Based on the testing of a single unit of the VRSS collision warning system and subject to the caveats discussed in Section 5.0, the following conclusions are offered:

1. In most cases, when a moving vehicle is being overtaken on a collision course at closing speeds of less than 25 mph, the VRSS will provide a useful audible warning. The probability of warning is very high if the target vehicle is a truck, but reduced if it is a passenger car, especially one with narrow, vertical taillight reflectors.
2. At highway speeds, the VRSS does not respond to fixed or slow-moving objects, nor to vehicles crossing perpendicular to the path of the test vehicle, nor to vehicles being overtaken at speeds greater than 30 mph.
3. When audible warnings occur, they are generally given at least five seconds prior to impact. At closing speeds below 10 mph, warning time increases to eight seconds or more. Averaged over all cases including those which produced no beeping, the average warning time was about three seconds at higher closing speeds and better than 5 seconds at lower speeds.
4. The average distance to target at which audible warnings occur ranges from around 60 feet at speeds below 50 mph to about 130 feet at speeds of 75 mph.
5. Road curvature, crest, sag or any other condition resulting in misalignment between the centerlines of test vehicle and target by more than a few feet can severely reduce warning time or eliminate it altogether.
6. Since VRSS performance characteristics are not user-adjustable, there is no way to increase warning time for degraded conditions such as wet or icy pavement or for driver impairment. The warning times provided by the VRSS are not sufficient for impaired drivers, nor for wet pavements except at low closing speeds, nor for icy surfaces at any speed.
7. The effects of precipitation and various sources of electromagnetic or radio-frequency interference on VRSS performance were outside the scope of this study. Similarly, the affects on driver behavior, such as, average following distance, were not explored.

APPENDIX 1: LISTING OF OBSERVED AND CALCULATED DATA

Column Definitions:

Variable	Type	Defintion
CASE	INTEGER	CASE NUMBER
MAKE	TEXT	MAKE OF VEHICLE
MODEL	TEXT	MODEL OF VEHICLE
SIZE	INTEGER	SIZE CLASS, AS DEFINED IN FIGURE 3.4-1
HO	INTEGER	HOUR, AS READ FROM THE STOPWATCH DISPLAY
MIN	INTEGER	MINUTE, AS READ FROM THE STOPWATCH DISPLAY
SECON	REAL	SECONDS AND HUNDRETHS FROM THE STOPWATCH
ASPEED	REAL	TEST VEH SPEED FROM MICRON SURVEYOR (mph)
CSPEED	CLOSING SPEED	CLOSING SPEED FROM RADAR GUN (mph)
TRWIDTH	INTEGER	TARGET WIDTH (mm) MEASURED ON SCREEN
BEEP	TEXT	Y=BEEPER ON
BRAKE	TEXT	Y=BRAKES APPLIED ON TEST VEHICLE
EVAS	TEXT	Y=EVASIVE MANEUVER INITIATED
TAWIDTH	REAL	ACTUAL WIDTH OF TARGET VEHICLE
TFDIST	REAL	DISTANCE TO TARGET (feet)
SSLAST	REAL	SECONDS SINCE LAST OBSERVATION, SAME CASE
ELAPSED	REAL	ELAPSED TIME SINCE FIRST OBSERVATION IN SAME CASE
OPT_RATE	REAL	CLOSING RATE (fps) CALCULATED BY THE OPTICAL METHOD
RAD_RATE	REAL	CLOSING RATE (fps) FROM THE RADAR GUN
RATE_RAT	REAL	OPTICAL RATE DIVIDED BY RADAR RATE
ERR	TEXT	Y-ERROR DETECTED BY RBASE
WARN	TEXT	DENOTES CASES FLAGGED FOR RECHECKING DATA ENTRY
NEW	TEXT	DEIGNATES FIRST LINE OF A NEW CASE
L1	TEXT	Y="ALERT" LIGHT ON
L2	TEXT	Y="WARNING" LIGHT ON
L3	TEXT	Y="DANGER" LIGHT ON
ADEQ	TEXT	DRIVER COMMENT, IF ANY, ON AEEQUACY OF WARNING
TSDIST	REAL	DISTANCE TO TARGET (seconds)
ACTSECS	REAL	CUMULATIVESECONDS SINCE FIRST LINE OF A GIVEN CASE
CLOSE	REAL	CLOSING SPEED (fps) AS SELECTED BY DECISION RULE IN SECTION 3.5
CL MPH	INTEGER	CLOSING SPEED (mph) AS SELECTED BY DECISION RULE IN SECTION 3.5
B WRN	TEXT	Y=WARNING SUFFICIENT FOR BRAKING ONLY (USED FOR TABLE 4.3-2)
WB WRN	TEXT	Y=WARNING SUFFICIENT FOR BRAKING ON WET PAVEMENT (USED FOR TABLE 4.3-3)
CLS 5	INTEGER	CLOSING SPEED TO NEAREST 5 MPH INCREMENT
ACT 5	INTEGER	ROAD SPEED TO NEAREST 5 MPH INCREMENT

CASE MAKE MODEL SIZE HO MIN SECCN ASPD SPEED TWENTH BEEP BRAKE EVAS TWENTH TRIST ELAPSED OPT RATE 3RD RATE RATE 3RD RATE ACTSEC CLOSE CL MPH 5 MIN 40 MIN 45 ACT 5 ACT 5

Table with columns: CASE, MAKE, MODEL, SIZE, HO, MIN SECCN, ASPD, SPEED, TWENTH, BEEP, BRAKE, EVAS, TWENTH TRIST, ELAPSED, OPT RATE, 3RD RATE, RATE 3RD RATE, ACTSEC, CLOSE CL, MPH 5 MIN, 40 MIN, 45 ACT, 5 ACT, 5. Rows include vehicle models like TRUCK, SUBARU, FORD ESCORT, CHEVROLET WAGON, etc.

CASE # SIZE HO NW SECOR ASPEED CSPEED TWDPTH DEEP BRAKE EVAS TWDPTH FIDIST SQUAST E-CAPDED OPT RATE ROD RATE RATE 5AT ER WARM NEW LI L2 L3 ABER TIDIST ACTISEE CLOSE CL NFR 5 WEN UP 5EN CLS 5 ACT 5

Table with columns: CASE #, SIZE, HO, NW SECOR, ASPEED, CSPEED, TWDPTH, DEEP, BRAKE, EVAS, TWDPTH, FIDIST, SQUAST, E-CAPDED, OPT RATE, ROD RATE, RATE 5AT, ER, WARM, NEW, LI, L2, L3, ABER, TIDIST, ACTISEE, CLOSE, CL, NFR 5, WEN UP, 5EN, CLS 5, ACT 5. Rows include vehicle models like FORD, CHEVROLET, PONTIAC, and various truck types.

CAR MAKE MODEL SIZE HP MIN SECND ASPEED CSPEED TDWTDTH REEP BRKAGE EVAS TDWTDTH TFDIST SGLAST ELAPSED OPT RATE AND RATE RATE RNT EGR WARR NEW LI L3 ADED TFDIST ACTISED CLOSE CL MPH 5 WRM HD WRM CLS 5 MET 3

Table with columns for Car Make, Model, Size, HP, Min, Secnd, Aspeed, Cspeed, Tdwtdth, Reep, Brkage, Evas, Tdwtdth, Tfdist, Sglast, Elapsed, Opt, Rate, And, Rate, Rate, Rnt, Egr, Warr, New, Li, L3, ADED, Tfdist, Actised, Close, Cl, Mph, 5, Wrm, Hd, Wrm, Cls, 5, Met, 3. Rows include models like Oldsmobile Cutlass, Buick Wildcat, Chevrolet Malibu, etc.

CASE MAKE MODEL SIZE HP MID SECS ASPEED CSPEED THROTTLE WEEP BRAKE EVMS TAYDITH TFOIST EBLAST ELAPSED OPT RATE RAD RATE RATE ERR WARM MEN LI L2 L3 ABERE TSDIST ACTSECT CLOSE CL MPH B WRM WB USR ELS S ACT 5

Table with columns for Case, Make, Model, Size, HP, Mid Secs, Aspeed, Cspeed, Throttle, Weep, Brake, Evms, Taydith, Tfoist, Eblast, Elapsed, Opt Rate, Rad Rate, Rate, Rate Err, Warm Men, Li, L2, L3, ABERE, TSDIST, ACTSECT, Close, CL, MPH, B, WRM, WB, USR, ELS, S, ACT 5.

CASE MAKE MODEL SIZE HO MIN SECND ASPED ESPEED TRMTH DEEP BRNKE EVAS TAVMTH TFDIST SELAST ELARGED CPT_RATE RAD_RATE_RAT_ERR WARM NEW L1 L2 L3 WROD TSSIST -CTISEE CLOSE CL MPH B WRM WRM WRM C.S 5 MIL: 5

Table with columns: CASE, MAKE, MODEL, SIZE, HO, MIN, SECND, ASPED, ESPEED, TRMTH, DEEP, BRNKE, EVAS, TAVMTH, TFDIST, SELAST, ELARGED, CPT_RATE, RAD_RATE_RAT, ERR, WARM, NEW, L1, L2, L3, WROD, TSSIST, -CTISEE, CLOSE, CL, MPH, B, WRM, WRM, WRM, C.S, 5 MIL: 5. Rows include models like CADILLAC, CHEVROLET, FORD, etc.

CAR MAKE MODEL SIZE HO MIN SECOR ASPED CRPEED TRWDTH DEEP BRNKE EVUS TWDIST FFDIST SLSAST ELAPSED OPT RATE INC RATE RATE JARI ERR WMAN WE+ L1 L2 L3 AREG TSDIST ACTISEE CLOSE CL MPH B WDM WHR CUS S ACT 3

Table with columns for Car Make, Model, Size, HO, Min, Secor, ASPED, CRPEED, TRWDTH, DEEP, BRNKE, EVUS, TWDIST, FFDIST, SLSAST, ELAPSED, OPT, RATE, INC, RATE, RATE, JARI, ERR, WMAN, WE+, L1, L2, L3, AREG, TSDIST, ACTISEE, CLOSE, CL, MPH, B, WDM, WHR, CUS, S, ACT, 3. Rows include models like OLDSMOBILE, CADILLAC, CHEVROLET, FORD, JEEP, etc.

CASE MAKE MODEL SITE NO. MIB ESCROW ASSESS CREDIT PAYMENT DEEP BRANK EVAS TANDARD IFFS: SELAST ESCROW P-I RATE AND RATE RATE PART ARE APRN NEW CL L D S ANE2 TSDIST RTSEED CLOSE CL RPM 3 SRN 48 SRN CLS 5 ACT 3

Table with columns: CASE NO., MAKE, MODEL, SITE NO., MIB, ESCROW, ASSESS, CREDIT, PAYMENT, DEEP, BRANK, EVAS, TANDARD, IFFS, SELAST, ESCROW, P-I, RATE, AND, RATE, RATE, PART, ARE, APRN, NEW, CL, L, D, S, ANE2, TSDIST, RTSEED, CLOSE, CL, RPM, 3, SRN, 48, SRN, CLS, 5, ACT, 3. Rows include vehicle models like SUICK, BUICK, FORD, ESCORT, MAZDA, etc.

CASE MAKE MODEL SIZE HO MIN SECND ASPED ESPED TAWITH TFDIST SELAST ELAPSED CPT JATE RAD RATE RAY ERR JARM MEX L1 L2 L3 ADED TQ1ST ACTSEC CLUSE CL MPH 5 CHG 4B JRM CLS 5 WCT 1

Table with columns: CASE MAKE, MODEL, SIZE, HO, MIN SECND, ASPED, ESPED, TAWITH, TFDIST, SELAST, ELAPSED, CPT, JATE, RAD, RATE, RAY, ERR, JARM, MEX, L1, L2, L3, ADED, TQ1ST, ACTSEC, CLUSE, CL, MPH, 5, CHG, 4B, JRM, CLS, 5, WCT, 1. Rows include vehicle models like TOYOTA, HONDA, NISSAN, etc.

Table with columns: CASE NAME, MODEL, SITE NO, MIN SECON ASPD, CSPEED, TRWIDTH, REEF, BRIDGE, EWAYS, TRWIDTH, TPDIST, SE, ASST, ELAPSED, OPT, RATE, RAD, RATE, SATE, EIR, DORN, NEU, LI, L2, L3, AMED, TBLIST, ACESSE, CLOSE, CL, MPH, 6, MPH, 45, 50, 60, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, 120, 125, 130, 135, 140, 145, 150, 155, 160, 165, 170, 175, 180, 185, 190, 195, 200, 205, 210, 215, 220, 225, 230, 235, 240, 245, 250, 255, 260, 265, 270, 275, 280, 285, 290, 295, 300, 305, 310, 315, 320, 325, 330, 335, 340, 345, 350, 355, 360, 365, 370, 375, 380, 385, 390, 395, 400, 405, 410, 415, 420, 425, 430, 435, 440, 445, 450, 455, 460, 465, 470, 475, 480, 485, 490, 495, 500, 505, 510, 515, 520, 525, 530, 535, 540, 545, 550, 555, 560, 565, 570, 575, 580, 585, 590, 595, 600, 605, 610, 615, 620, 625, 630, 635, 640, 645, 650, 655, 660, 665, 670, 675, 680, 685, 690, 695, 700, 705, 710, 715, 720, 725, 730, 735, 740, 745, 750, 755, 760, 765, 770, 775, 780, 785, 790, 795, 800, 805, 810, 815, 820, 825, 830, 835, 840, 845, 850, 855, 860, 865, 870, 875, 880, 885, 890, 895, 900, 905, 910, 915, 920, 925, 930, 935, 940, 945, 950, 955, 960, 965, 970, 975, 980, 985, 990, 995. Each row contains data for a specific case, including model (e.g., FORD TRUCK, BUICK TRUCK), site number, speed metrics, and various performance indicators.

CASE NAME MODEL SIZE NO MIN BEGIN ASPEED TRAVLTH KEEP BRAKE EVAS TRAVLTH TRFST SELEST ELAPSED DPT RATE RAD RATE RATE ERR JCTN NEW L3 L2 L3 ADGC TRFST ACTSEC CLOSE CL WPH 9 WPH 49 WPH 15 5 ACT 1

Table with columns: CASE NAME, MODEL, SIZE, NO, MIN, BEGIN, ASPEED, TRAVLTH, KEEP, BRAKE, EVAS, TRAVLTH, TRFST, SELEST, ELAPSED, DPT, RATE, RAD, RATE, RATE, ERR, JCTN, NEW, L3, L2, L3, ADGC, TRFST, ACTSEC, CLOSE, CL, WPH, 9, WPH, 49, WPH, 15, 5, ACT, 1. Rows include vehicle models like ESCORT, CHEVROLET IMPALA, FORD, BUICK, etc.

CASE PRICE MODEL SIZE HD MIN SECIN ASPED CSPEED TRMTRDIN BEEP BRAKE EVAS TMRDTH TFOIST SELAST ELAPSED OPT RATE HBD RATE RATE SRT EAR WDR NEW LI L2 L3 NEED TESTSET RETSEC CLOSSE CL MFA 6 JRN WD WDR LIS 5 AC 3

Table with columns for Case Price, Model, Size, HD, Min Secin, Asped, Cspeed, Trmtrdin, BEEP, Brake, Evas, Tmrdrth, Tfoist, Selast, Elapsed, Opt Rate, Hbd Rate, Rate, Srt Ear, Wdr New, Li, L2, L3, Need, Testset, Retsec, Closse, Cl, Mfa 6, Jrn Wd, Wdr, Lis 5, Ac 3. Rows include models like 237. BUSS, 238. FORD, 239. FORD, etc.

CASE NAME MODEL SITE NO HIGH SECON ASPED CSPEED TOWMTH DEEP BRNKE EVMS TADWTH TFDIST SELBST ELAPSED CFT RATE MAD RATE RATE RATIO EGR WARM NEW L1 L2 L3 ADED TSDIST ACTSEED CLOSE J1 MFA 8 WRM 48 WRM CUS 5 ACT 5

Table with columns: CASE NAME, MODEL, SITE NO, HIGH SECON ASPED, CSPEED, TOWMTH, DEEP BRNKE EVMS, TADWTH, TFDIST, SELBST, ELAPSED, CFT, RATE, MAD, RATE, RATE, RATIO, EGR, WARM, NEW, L1, L2, L3, ADED, TSDIST, ACTSEED, CLOSE, J1, MFA, 8, WRM, 48, WRM, CUS, 5, ACT, 5. Rows include models like FORD, CHEVROLET CAMARO, TOYOTA SUPRA, and CHEVROLET CAMARO.

Table with columns: CASE MAKE, MODEL, SIZE, HD, RM, SEC'D, ASPEED, CSPEED, TRWIDTH, TRMITE, BEEP, BRAKE, EVAS, TRWIDTH, TFDIST, SBLST, ELWASED, OPT, RATE, RAD, RATE, RATE, RAT, ERR, WASH, NEW, L1, L2, L3, AXED, TSDIST, ACTISEC, CLOSE, IN, RM, WASH, D.S., ACT, S.

Table with columns: 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100.

CAR MAKE	MODEL	SIZE	NO	MIN	SEC	ASPCD	CEASED	TRMTRM	DEEP	BRACE	EVAS	TAMTRM	TDIST	SUBST	ELAPSED	OPT	RAD	RATE	RAT	ERR	WRN	HEM	L1	L3	AORD	TDIST	ADJSEC	CLOSE	EL	WRN	MB	WRN	CLS	S	ACT
331. VOLKSWAGEN	SCARABO	2	7.	2.75	70.4	12.	46.	Y	Y	Y	Y	Y	Y	Y	0.33	23.586	17.6	1.376	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	76.	
332. VOLKSWAGEN	SCARABO	2	7.	3.69	79.	12.	56.	Y	Y	Y	Y	Y	Y	Y	1.27	15.474	17.6	0.873	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	76.	
333. VOLKSWAGEN	SCARABO	2	7.	4.76	87.1	11.	75.	Y	Y	Y	Y	Y	Y	Y	2.34	15.842	16.267	0.919	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	65.	
334. TOYOTA	TERCEL	4	7.	78.11	63.1	10.	30.	Y	Y	Y	Y	Y	Y	Y	0.	0.	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	65.	
335. TOYOTA	TERCEL	4	7.	24.31	63.3	10.	31.	Y	Y	Y	Y	Y	Y	Y	0.4	10.01	14.687	0.682	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	65.	
336. TOYOTA	TERCEL	4	7.	25.48	63.1	9.	33.	Y	Y	Y	Y	Y	Y	Y	1.37	14.153	13.933	1.016	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	65.	
337. TOYOTA	TERCEL	5	7.	30.47	69.	10.	31.	Y	Y	Y	Y	Y	Y	Y	6.81	10.03	13.2	0.741	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	65.	
338. TOYOTA	TERCEL	5	7.	31.48	70.	10.	31.	Y	Y	Y	Y	Y	Y	Y	0.01	0.	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	65.	
339. TOYOTA	TERCEL	5	7.	31.48	70.	10.	31.	Y	Y	Y	Y	Y	Y	Y	0.01	0.	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	65.	
340. LINCOLN	MERCURY	3	8.	40.55	72.5	14.	30.	Y	Y	Y	Y	Y	Y	Y	4.68	11.973	13.2	0.907	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	65.	
341. LINCOLN	MERCURY	3	8.	46.92	72.5	14.	33.	Y	Y	Y	Y	Y	Y	Y	0.	0.	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	65.	
342. LINCOLN	MERCURY	3	8.	41.85	72.5	14.	38.	Y	Y	Y	Y	Y	Y	Y	71.	109.7	0.95	1.5	17.823	20.333	0.688	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	15.	75.	
343. LINCOLN	MERCURY	3	8.	43.32	72.5	13.	51.	Y	Y	Y	Y	Y	Y	Y	71.	78.812	1.47	2.77	18.988	19.8	0.958	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	15.	75.	
344. LINCOLN	MERCURY	3	9.	3.55	71.	22.	28.	Y	Y	Y	Y	Y	Y	Y	0.	0.	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
345. LINCOLN	MERCURY	3	9.	45.49	72.5	18.	40.	Y	Y	Y	Y	Y	Y	Y	0.	0.	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.
346. LINCOLN	MERCURY	3	9.	43.82	72.5	13.	42.	Y	Y	Y	Y	Y	Y	Y	0.	0.	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.
347. LINCOLN	MERCURY	3	9.	46.72	72.5	15.	60.	Y	Y	Y	Y	Y	Y	Y	0.33	15.582	22.733	0.684	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11.	10.	70.
348. LINCOLN	MERCURY	3	9.	47.49	72.5	15.	60.	Y	Y	Y	Y	Y	Y	Y	1.3	16.924	19.8	0.855	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	15.	75.	
349. LINCOLN	MERCURY	3	10.	36.52	71.	8.	32.	Y	Y	Y	Y	Y	Y	Y	0.	0.	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	15.	75.	
350. LINCOLN	MERCURY	3	10.	36.89	71.	8.	33.	Y	Y	Y	Y	Y	Y	Y	0.37	10.438	11.733	0.907	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
351. LINCOLN	MERCURY	3	10.	36.95	71.	8.	33.	Y	Y	Y	Y	Y	Y	Y	0.43	0.	11.733	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
352. LINCOLN	MERCURY	3	10.	35.63	72.1	10.	38.	Y	Y	Y	Y	Y	Y	Y	1.04	18.417	13.2	1.355	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
353. LINCOLN	MERCURY	3	10.	37.05	72.5	11.	45.	Y	Y	Y	Y	Y	Y	Y	2.33	14.18	15.4	0.921	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
354. LINCOLN	MERCURY	4	11.	30.31	73.2	16.	52.	Y	Y	Y	Y	Y	Y	Y	0.	0.	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
355. LINCOLN	MERCURY	2	15.	3.77	73.2	19.	34.	Y	Y	Y	Y	Y	Y	Y	0.	0.	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
356. LINCOLN	MERCURY	2	15.	34.8	64.9	14.	23.	Y	Y	Y	Y	Y	Y	Y	0.	0.	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
357. LINCOLN	MERCURY	2	15.	35.28	64.9	14.	24.	Y	Y	Y	Y	Y	Y	Y	0.46	14.637	20.333	0.811	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	65.	
358. LINCOLN	MERCURY	2	15.	36.17	64.9	14.	24.	Y	Y	Y	Y	Y	Y	Y	1.21	23.894	20.333	1.241	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	65.	
359. LINCOLN	MERCURY	3	15.	37.77	69.5	15.	38.	Y	Y	Y	Y	Y	Y	Y	2.97	23.744	21.267	1.117	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	15.	70.	
360. LINCOLN	MERCURY	3	15.	32.49	81.1	10.	41.	Y	Y	Y	Y	Y	Y	Y	0.	0.	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
361. LINCOLN	MERCURY	3	15.	35.32	81.5	9.	43.	Y	Y	Y	Y	Y	Y	Y	0.33	7.367	7.333	1.003	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
362. LINCOLN	MERCURY	3	15.	35.52	81.7	0.	43.	Y	Y	Y	Y	Y	Y	Y	0.3	7.607	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
363. LINCOLN	MERCURY	3	15.	34.29	62.	0.	44.	Y	Y	Y	Y	Y	Y	Y	1.5	1.625	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	60.	
364. LINCOLN	MERCURY	2	16.	21.63	71.	13.	32.	Y	Y	Y	Y	Y	Y	Y	0.	0.	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	60.	
365. LINCOLN	MERCURY	2	16.	23.12	72.1	19.	43.	Y	Y	Y	Y	Y	Y	Y	0.3	25.613	11.	2.328	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
366. LINCOLN	MERCURY	2	16.	23.99	69.	23.	41.	Y	Y	Y	Y	Y	Y	Y	1.27	26.53	13.733	1.904	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
367. LINCOLN	MERCURY	3	17.	4.53	85.2	5.	41.	Y	Y	Y	Y	Y	Y	Y	2.14	32.972	28.5	1.153	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
368. LINCOLN	MERCURY	3	17.	7.2	85.	0.	44.	Y	Y	Y	Y	Y	Y	Y	0.	0.	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
369. LINCOLN	MERCURY	3	17.	7.8	84.5	0.	44.	Y	Y	Y	Y	Y	Y	Y	0.6	1.27	3.282	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	55.	
370. LINCOLN	MERCURY	3	17.	10.8	85.	0.	41.	Y	Y	Y	Y	Y	Y	Y	3.	4.27	3.968	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	55.	
371. LINCOLN	MERCURY	3	19.	12.15	83.7	8.	41.	Y	Y	Y	Y	Y	Y	Y	0.36	16.904	11.733	0.373	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	65.	
372. LINCOLN	MERCURY	3	19.	13.12	84.3	5.	48.	Y	Y	Y	Y	Y	Y	Y	1.33	7.531	9.533	0.754	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	65.	
373. LINCOLN	MERCURY	2	20.	23.19	74.5	2.	93.	Y	Y	Y	Y	Y	Y	Y	0.	0.	0.	0.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
374. LINCOLN	MERCURY	2	20.	23.17	74.5	2.	94.	Y	Y	Y	Y	Y	Y	Y	0.51	2.794	2.933	0.953	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	
375. LINCOLN	MERCURY	2	20.	24.53	72.5	2.	92.	Y	Y	Y	Y	Y	Y	Y	1.44	7.844	2.933	2.674	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10.	70.	

CAR ANTI-COLLISION
 DATE 11/25/87
 TIME 18:18